Lehough

Anthrax omitted.

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3 chap Colon typhoid

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A TEXT-BOOK OF GENERAL BACTERIOLOGY

BY

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FULLY ILLUSTRATED

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TO

MY MOTHER

THIS BOOK IS

AFFECTIONATELY DEDICATED

PREFACE TO THE SECOND EDITION

In preparing the second edition of this book, I have corrected a few errors, repaired some omissions, and added several new sections. During the short time that has elapsed since the book first went to the printers there has been great and continued activity in bacteriologic research. It is perhaps not possible in all cases to estimate the full significance of the reported observations, but the attempt has been made to include in the text at least some of the newly won data. I am especially indebted to friends who have read critically certain sections of the book, and so have aided me in keeping abreast of current progress. I wish also to express my thanks to all those readers—many of them unknown to me—who have written to me kindly words of appreciation and encouragement since the book first appeared. These spontaneous and entirely unexpected expressions of approval have made the revision, as well as the original writing, seem worth while.

Chicago, *August*, 1910.

PREFACE

This book is the outgrowth of lectures given to students in the University of Chicago during the past few years. The subject is one that the writer believes should find a place in every general scientific course. Bacteriology is chiefly of professional interest to the medical student, but the subject also bears technical relations to household administration, to agriculture, to sanitation and sanitary engineering and to various industries and technological pursuits. For the general scientific student and reader bacteriology presents certain aspects that tend to widen the outlook upon a variety of human interests.

It need hardly be said that within the compass of this work an exhaustive treatment of all sides of bacteriology is impossible. The needs of the advanced worker can be met only—and that but in part—by such monumental special treatises as the Handbuch der Pathogenen Mikroörganismen, edited by Kolle and Wassermann, and the Technische Mykologie, edited by Lafar. A general introduction to the subject, however, with some regard for perspective and with emphasis on general rather than on special questions has seemed worth attempting.

The reader who wishes to acquire greater familiarity with the subject will find some bibliographical references given as a sort of first aid to the investigator. These include references to some articles of classic or historic interest, to some giving valuable summaries or bibliographies of important subjects and to a few in fields where investigation is very active or opinions considerably at variance. No pretension to completeness is made.

The fundamental principles and methods of laboratory work are treated as fully as seems desirable in a book of this class. The tendency manifested in all the natural sciences towards the elaboration of special laboratory manuals and guides has much in its favor. A number of such guides for bacteriology are in existence, among

which may be mentioned the excellent manuals of Frost, Gorham, Heinemann, Moore and Novy, to mention only American authors. In any case a proper familiarity with laboratory methods can be gained only with the assistance of a skilled laboratory instructor possessed of individuality and resource.

I have been greatly assisted by many friends and colleagues in the preparation of this work, and to all I wish to express my cordial thanks. I am particularly indebted to Professors Ludvig Hektoen and N. McL. Harris and to Drs. P. G. Heinemann and Mary Hefferan, who have helped me in a variety of ways. Finally I would acknowledge my deep obligation to my wife, who has aided me in the preparation of the book at every point, especially in the revision of the manuscript and proof-sheets.

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General Bacteriology

CHAPTER I

INTRODUCTION

The Discovery of Bacteria.—The belief that there are living organisms too small to be seen by the unaided human eye, and that such invisible organisms play an important part in various natural phenomena, has found utterance many times since the dawn of history. Several of the philosophers of antiquity were bold enough to surmise that such organisms existed, and some writers even framed their speculations on this subject in phrases that seem like far-seeing anticipations of modern discoveries. Interesting in some degree as these speculations are, they appear to have had no influence whatever upon the course of scientific investigation, and to have been let fall at random by their authors, like hundreds of similar conjectures, without any real basis in observation or experiment. The fact is that prior to the work of the Dutch microscopist, Anton van Leeuwenhoek, in the latter part of the seventeenth century, definite ocular evidence for such a belief did not exist. Leeuwenhoek (1632–1723), who was a skilled lens-maker of Delft, Holland, spent many years in examining through his microscope a great variety of natural objects, with unremitting industry if without system, and in the course of his observations chanced to come across the organisms now known as bacteria. In a letter to the Royal Society of London, dated September 14, 1683, he records in these words his observations upon some tartar scraped from the teeth and mixed with water: "I saw with wonder that my material contained many tiny animals which moved about in a most amusing fashion; the largest of these (*A*, Fig. 1) showed the liveliest and most active motion, moving through the water or saliva as a fish

of prey darts through the sea; they were found everywhere, although not in large numbers. A second kind was similar to that marked *B* (Fig. 1). These sometimes spun around in a circle like a top, and sometimes described a path like that shown in *C–D* (Fig. 1); they were present in larger numbers. A third kind could not be distinguished so clearly; now they appeared oblong, now quite round. They were so very small that they did not seem larger than the bodies marked *E*, and besides they moved so rapidly that they were continually running into one another: they looked like a swarm of gnats or flies dancing about together. I had the impression that I was looking at several thousands in a given part of the water or saliva mixed with a particle of the material from the teeth no larger than a grain of sand, even when only one part of the material was added to nine parts of water or saliva. Further, the greater part of the material consisted of an extraordinary number of rods, of widely different lengths, but of the same diameter. Some were curved, some straight, as is shown in *F*; they lay irregularly and were interlaced. Since I had previously seen living animalcules of this same kind in water, I endeavored to observe whether there was life in them, but in none did I see the smallest movement that might be taken as a sign of life." Leeuwenhoek supplemented his observations with drawings, and there is no doubt that he was the first to see bacteria and describe them accurately.

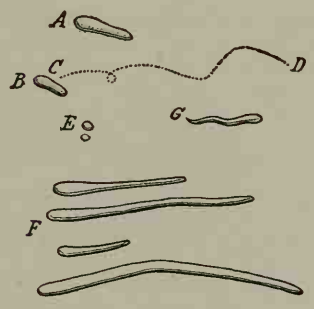


Fig. 1.—The first pictorial representation of bacteria. Leeuwenhoek, 1683 (Löffler).

The Origin of Bacteriology.—Leeuwenhoek's observations remained practically isolated and without fruit for nearly a century. It was not until 1786 that the work of the Danish zoölogist, O. F. Müller, added anything of importance to the knowledge of bacteria. Müller recognized clearly the difficulties of studying such minute organisms. "The difficulties," he writes, in words that still appeal to the modern bacteriologist, "that beset the investigators of these microscopic animals are countless; the sure and definite determination [of species] requires so much time, so much acumen of eye and judgment, so much perseverance and practice, that there is hardly anything else so difficult." Despite the obstacles, how-

ever, Müller succeeded in discovering many structural details of which his predecessors had been ignorant. Indeed, he succeeded in depicting several kinds of bacteria so accurately that they can be identified today as belonging to one or another of the chief group-forms.

Another unequivocal advance was made by Ehrenberg (1795–1876). His principal work upon the "infusion animals," "infusoria," or "Infusionstierchen," as the animalcules found in infusions of hay, meat, and other organic substances were termed, was published in 1838, and brought together much more definite and detailed information concerning bacteria than had previously been secured. The chief merit of Ehrenberg's work lay in the system that it introduced into the study of micro-organisms. This investigator was able to establish a number of different groups among the organisms now called bacteria, and recognized clearly the fundamental differences between the larger forms, such as the screw-shaped or spirally-twisted organisms, and certain of the true protozoa with which they had heretofore been classed. Some of the names which Ehrenberg conferred upon his "infusion animals," such as bacterium and spirillum, are still current in bacteriologic nomenclature, although with changed signification.

In the two or three decades succeeding Ehrenberg's work considerable knowledge was amassed concerning the mode of development and physiology of bacteria, as well as their position in biologic classification, but the labors of Dujardin, Perty, Cohn, Nägeli, and others, although important, are quite overshadowed by the work of Pasteur.

Up to the period of Pasteur's investigations the rôle played by bacteria in various familiar natural processes, such as putrefaction, decay, and fermentation, had been, perhaps, vaguely suspected, but had not received conclusive demonstration. The memorable researches of Pasteur (1822–1895) upon spontaneous generation and fermentation imparted to the study of bacteria a broad biologic importance that it had not hitherto possessed. Bacteria and kindred micro-organisms were shown to be responsible for setting in motion and carrying out many every-day processes, the nature of which had not before been understood or which had been incorrectly assigned to "the oxygen of the air" or to other inorganic

agencies. Putrefaction and decay were shown by Pasteur to be not fields for the "spontaneous generation" of life, but manifestations of chemical disintegration due to the metabolic activities of micro-organisms engaged in satisfying their need of food. Fermentation was not due, as Liebig for a time maintained, to the presence of dead and dying yeast-cells which in the course of their own molecular disintegration toppled over and dragged down certain complex organic molecules with which they were in contact, but, on the contrary, was caused by the effort of living and growing yeast-cells to satisfy their nutritional requirements.

It was almost entirely through the work of Pasteur that bacteria and their allies emerged from their relative obscurity as organisms chiefly of interest to the professional biologist and took a conspicuous position in natural science as a group of organisms whose activities and capabilities were full of a far-reaching significance for all mankind. If any one man can be looked upon as the founder of the science of bacteriology, that man is surely Louis Pasteur.

The profound importance of Pasteur's researches has been universally recognized. Lord Lister, whose own name is inseparably connected with the triumphs of antiseptic surgery, thus addressed Pasteur in 1892 at the latter's jubilee celebration: "Truly, there does not exist in the entire world any individual to whom the medical sciences owe more than they do to you. Your researches on fermentation have thrown a powerful beam, which has lightened the baleful darkness of surgery, and has transformed the treatment of wounds from a matter of uncertain and too often disastrous empiricism into a scientific art of sure beneficence. Thanks to you, surgery has undergone a complete revolution, which has deprived it of its terrors and has extended almost without limit its efficacious power."

Tyndall also has expressed in forcible words the sweeping change that was wrought in all conceptions of disease through the work of Pasteur. "We have been scourged by invisible thongs, attacked from impenetrable ambuscades, and it is only today that the light of science is being let in upon the murderous dominion of our foes."

If the researches of Pasteur mark the beginning of bacteriology, those of Robert Koch must be regarded as establishing bacteriology

on the basis of an independent biologic science. In 1876 Koch brought forward convincing evidence that a specific bacterium (B. anthracis) was the cause of a specific disease in cattle (anthrax or splenic fever). The nature of the proof submitted in support of this view was so conclusive that it drew the attention of the scientific world, and incited many investigators to undertake similar researches along the line of the "germ theory." In 1882 Koch further conferred an inestimable service upon practical workers in this field by his invention and application of solid culture-media, a technical device by which it became possible to isolate single species of bacteria and obtain them in pure culture. Prior to the introduction of solid media the isolation of a single species of microbe involved much difficulty and almost always a certain measure of uncertainty. So long as investigators were often not wholly secure as to whether they were dealing with a single species of bacteria or with a mixture of different kinds, the methods of work lacked uniformity and precision, and all general conclusions were hazardous. When, however, Koch showed how to obtain the descendants of a single living cell or cluster of cells free from extraneous matter and without admixture with other organisms, immediate advance became possible. It cannot be a mere coincidence that the great discoveries in bacteriology followed fast on the heels of this important technical improvement, and it is perhaps not too much to claim that the rise of bacteriology from a congeries of incomplete although important observations into the position of a modern biologic science should be dated from about this period (1882).

The Scope of Bacteriology.—As in other growing sciences, so in bacteriology a noticeable differentiation has occurred. The relation of bacteria to disease early took a conspicuous place among the subjects included within the scope of the new science, and it is highly probable that the side of bacteriology bearing upon the science of pathology and the art of medicine will always remain, what it is today, its most broadly important aspect. There is at present a tendency for the workers in this field to specialize either along strictly pathologic or along hygienic lines. In pathologic bacteriology consideration is given chiefly to the effects produced upon the animal body by the presence of bacteria and their toxins, to the distribution of the germs within the body, and to the reac-

tions, defensive and otherwise, evoked by bacterial invasion. Hygienic or sanitary bacteriology deals more particularly with the channels by which bacteria leave the human body and pass into the outer world, with the mode and duration of life of disease germs in water, soil, and air, and with the avenues by which these disease germs are able again to approach and infect healthy individuals. No sharp line can be drawn between pathologic and sanitary bacteriology. A common meeting-ground of great importance is found in the researches upon immunity, where it is shown that the resistance of the animal organism to infection depends both upon the nature of the tissues with which the germ comes in contact, and upon the hygienic surroundings of the organism with reference to food, temperature, moisture, and the like, as well as upon the inherited qualities of the various groups of body-cells. The interweaving of pathologic and sanitary bacteriology, of preventive and curative medicine, is illustrated with especial clearness in the chapter upon diphtheria (Ch. XV).

Although, from a practical point of view, the part played by bacteria in the causation of disease in man must be admitted to be of surpassing importance, it must not be forgotten that bacteria exert a marked influence upon the welfare of mankind in many other directions.

Bacteria not only disintegrate and destroy dead bodies, and attack and kill living organisms, but some forms are also constructive to a high degree, and translate important chemical elements, like nitrogen and carbon, from unavailable combinations into substances that can be utilized by higher forms of plant life.

It has been discovered, for example, that certain kinds of bacteria profoundly modify the composition of the soil and the character of crops, and are hence of importance to the agriculturist; that other kinds of bacteria impart the characteristic flavors or aromas to butter, cheese, and other dairy products; and that still others determine the success or failure of various industrial processes, such as the retting of flax, the tanning of hides, and, perhaps, the curing of tobacco. It is believed by many that the applications of bacteriology to various industries and manufactures and to agriculture are likely to become much more numerous in the near future.

Underlying all the applications of bacteriology are certain fun-

damental facts and principles concerning the structure, mode of development, and general physiologic requirements and capabilities of bacteria themselves. This subject-matter constitutes the groundwork of bacteriology, and is essential not only to a proper comprehension of the present practical applications of bacteriology, but also to the further development of the science.

Biologic Significance.—The fact should not be overlooked that bacteriology owes its present important place among the biologic sciences quite as much to its general scientific significance as to the success of its practical applications. It has been often pointed out that the change in man's conceptions of the world around him that has been produced by bacteriology is so sweeping as almost to deserve the term revolutionary. Up to the middle of the nineteenth century the character of many of the most familiar of natural processes, such as decay, fermentation, and the like, was entirely misunderstood; contemporary spontaneous generation of at least the lower forms of life was the generally accepted belief of most scientific men; infectious diseases were not sharply differentiated from one another and the most fantastic hypotheses were advanced to explain their existence. Although the great mass of material phenomena elsewhere had been brought into apparent orderliness and system, here was a region in which the unscientific imagination rioted in mystery and extravagance. The penetration of this realm of obscurity by the discoveries of bacteriology gave the human race for the first time in its history a rational theory of disease, dispelled the myths of spontaneous generation, and set the process of decay and kindred phenomena in their true relation to the great cycle of living and non-living matter.

The new conception of the microscopic underworld which bacteriology brought into biologic science must be reckoned as a conspicuous landmark, and, in so far as it has changed the attitude of man toward the universe, should be regarded as one of the most important triumphs of natural science.

Some of the aspects of the historical development of bacteriology are admirably treated in two essays by Huxley: "Discourses, Biological and Geological," New York, 1894 (Yeast, p. 110; Biogenesis and Abiogenesis, p. 229). A fairly detailed history of bacteriology to 1887 has been written by Löffler, entitled "Vorlesungen über die Geschichtliche Entwickelung der Lehre von den Bacterien," Leipzig, 1887.

CHAPTER II

METHODS OF STUDYING BACTERIA

The ubiquity of bacteria, their minute size, and their occasional high resistance to external influences gave them a prominent place in the controversy that raged in the middle of the nineteenth century over the question of spontaneous generation. It was then assumed that when organic fluids and infusions of various kinds were heated to the temperature of boiling water, all life was killed. If, therefore, bacteria appeared in infusions which had first been heated and afterward supposedly protected against the ingress of micro-organisms from the air, their advent was hailed as an instance of spontaneous generation. It was, perhaps, not unreasonable to suppose that if any kind of life developed from non-living matter, this might be expected to occur among organisms so relatively simple in structure as bacteria. The progress of investigation, however, showed that it was not altogether an easy matter either to free organic fluids and extracts from bacteria, or to prevent the entrance of germs from the air. In the endeavor to overcome these two difficulties, a rudimentary bacteriologic technic was developed which laid the foundation for the later discoveries of Pasteur and Koch. Thus the discovery that cotton plugs, while they allow the air to circulate freely, are an effectual barrier to the floating particles in the air (Schröder and v. Dusch, 1854) was the direct outcome of experiments on spontaneous generation. Modern bacteriologic technic still makes extensive use of the cotton plug in protecting culture-media, etc., against atmospheric contamination.

The need of freeing glassware, instruments, and nutrient media from all forms of life before beginning bacterial experimentation of any sort is the central point of bacteriologic method. The principles of sterilization may therefore first be considered.

Sterilization of Glassware and Instruments.—As a preliminary to sterilization, glassware, especially when new, should be

thoroughly cleansed by boiling in soapsuds, or by soaking for an hour or more in the chromic-acid cleaning mixture.

Potassium dichromate	60 parts
Water	300 "
Concentrated sulfuric acid	460 "

The sulfuric acid is added slowly with constant stirring.

After thoroughly rinsing and drying, test-tubes and flasks are plugged with a good quality of ordinary non-absorbent cotton and placed without crowding in a hot-air sterilizer. The best hot-air sterilizers, like the Lautenschläger pattern (Fig. 2),

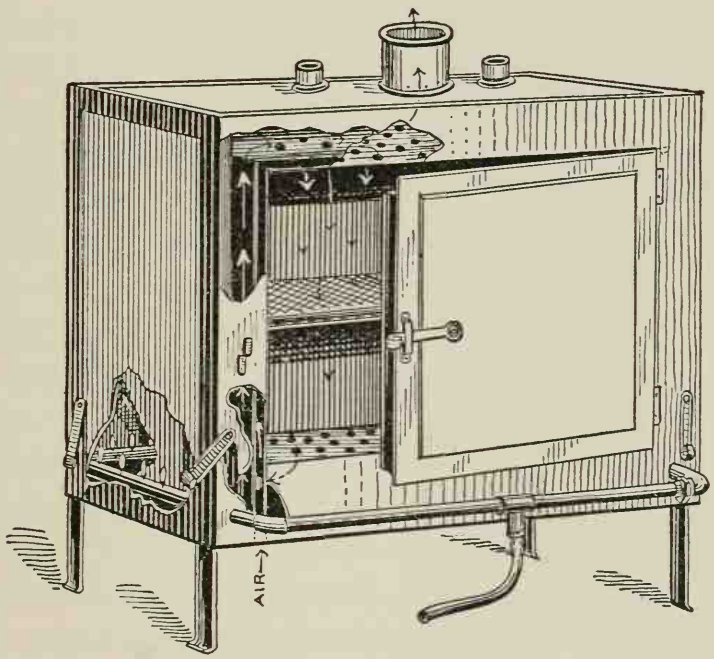


Fig. 2.—Lautenschläger hot-air sterilizer.

are fitted with thermometers and give a uniform temperature throughout. Experiments have shown that maintenance of a temperature of 170° C. for forty-five minutes to one hour is sufficient to destroy all bacteria, even those in the resistant spore-stage. Many ovens and hot-air sterilizers need to be carefully watched, because the temperature varies considerably in different parts. In the absence of exact temperature-control a very slight browning of the cotton is sometimes taken as evidence that the necessary temperature has been reached. Too great charring must be avoided.

Instruments may be sterilized directly in the flame or wrapped in manila paper and heated in the hot-air sterilizer at 170° C. for one hour. Scissors, forceps, knives, hypodermic needles, metal

syringes, etc., should be boiled in water or in a 1 per cent. soda solution for three to five minutes before they are used, and after use boiled again thoroughly for disinfection. Platinum wires and loops for transferring bacteria from cultures are heated directly in a gas or alcohol flame until red-hot, and then allowed to cool so that they will not injure the bacteria touched by them.

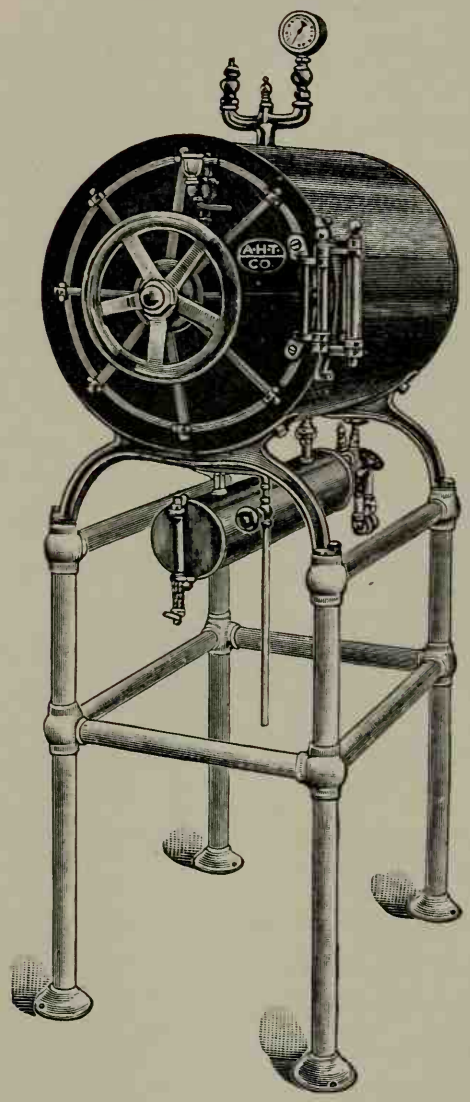


Fig 3.—Autoclave. Horizontal form.

Rubber stoppers and tubing should be cleansed with soap and water and allowed to stand for one hour in 1 : 1000 mercuric chlorid solution, then washed with sterile water before using.

Autoclave Sterilization.—In order to effect immediate sterilization of culture-media, steam under pressure, and hence at a temperature higher than 100° C., is often used. The apparatus for this purpose, known as an autoclave, consists of a steam cylinder with a top fastened down by nuts and screws, a pressure-gage, safety-valve, and thermometer. A large Bunsen burner underneath supplies the heat (Fig. 3). A temperature of 120° C. for five minutes is usually sufficient to sterilize completely all tubed media; media in bulk should be heated for fifteen minutes. Care is necessary in the manipulation of the autoclave. (1) Baskets of tubes or flasks should not be piled on top of one another so that the stoppers become wet from the dripping. (2) All air should be allowed to escape before screwing down the stop-cock, as a mixture of steam and air does not reach the temperature indicated by the gage. (3) The pressure should be allowed to drop to zero before the stop-cock is opened, as a sudden removal

of pressure may cause an explosive evolution of steam which will blow the stoppers and media out of the flasks and tubes.

The autoclave is much used for sugar-free broth and agar, and for sterilizing discarded cultures, and test-tubes and apparatus after use. It is possible to heat gelatin in the autoclave at 120° for five minutes and still obtain solidification if after removing the gelatin from the autoclave it is placed at once in an ice-box. Blood-serum and all media containing carbohydrates are apt to undergo important chemical changes from prolonged heating at high temperatures, and are best sterilized by the discontinuous method.

Discontinuous Sterilization.—As just stated, certain kinds of media become to some degree unfit for bacteriologic work if subjected to the high temperature reached in the autoclave. The use of a lower temperature is hence desirable. Most bacteria are quickly killed by boiling. A serious drawback, however, to the use of simple boiling is the fact that very resistant bacterial spores are sometimes not killed even when boiled for several hours. The method of discontinuous sterilization is consequently adopted in some cases. Any simple apparatus may be used for this purpose, such as a covered kitchen steamer over a pot of boiling water. A device in common use in the laboratory is the Arnold steam sterilizer, which is constructed with a false bottom, so that a minimum volume of water is heated to produce steam quickly, while the main tank is constantly fed by the water of condensation, which is caught and collected by an outer jacket.

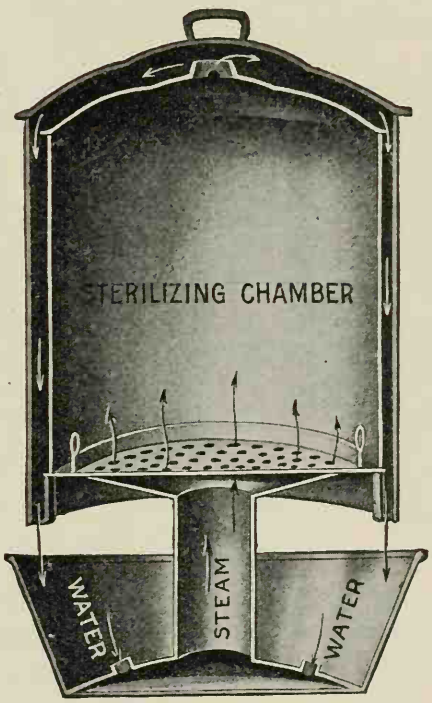


Fig. 4.—Arnold steam sterilizer (Fowler).

By the discontinuous method the medium is heated the first day for fifteen to twenty minutes after the steam has filled the sterilizer. The steaming process is repeated on one or two successive days, the medium being kept at 20° C. in the intervals. This

method aims to kill by each steaming all those bacteria that are in the vegetative form, while the intervals of twenty-four hours are supposed to allow time for the resistant spores to develop into vegetative forms, which are then destroyed at the next steaming. The method is not always successful. Smith* has pointed out that the spores of anaërobes may sometimes fail to germinate during the twenty-four-hour intervals in liquid media, such as shallow layers of broth or milk where the fluid is well oxygenated, but remain dormant until favorable anaërobic conditions come about through the introduction and growth of film-producing organisms, when the spores germinate and a mixed culture is produced. Most flasks of media will remain sterile after four steamings if the intervals between are lengthened to forty-eight hours, but the autoclave may have to be brought into play in very obstinate cases.

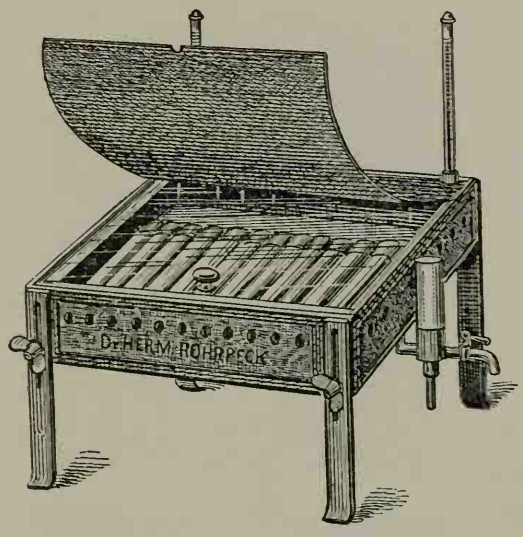


Fig. 5.—Koch's apparatus for coagulating and sterilizing blood-serum (McFarland).

The method of discontinuous sterilization is also employed for sterilization of certain body-fluids, such as blood-serum, which cannot be subjected to high temperature without coagulating. A temperature of 53° to 70° C. for one hour each on six successive days in the inspissator will, with few exceptions, completely sterilize tubes of blood-serum (Fig. 5).

Preparation of Culture-media.—The food necessary for most bacterial organisms is not of a highly complicated nature. Many species find suitable conditions for nourishment and multiplication if a small amount of simple nitrogen and carbon compounds and some salts and water are present. A slightly acid reaction to phenolphthalein (equivalent to a neutral or slightly alkaline reaction to litmus) and a temperature of about 20° C. afford excellent opportunity for the growth of micro-organisms in the presence of almost any ordinary food-stuff. It is largely by means of varia-

* Smith: Jour. Exper. Med., 1898, 3, p. 647.

tions in the behavior of bacteria toward different carefully prepared nutrient substances that bacteriologists are able to differentiate the bacterial species. Many different culture-media have been devised which are in general laboratory use. The most common of these have for their basis an extract or decoction of meat to which a small amount of peptone is added. Koch found that by the addition of gelatin to this meat-peptone broth a solid, transparent medium could be obtained which greatly facilitated the study of the development of organisms. Gelatin, however, does not remain solid at 37° C., a temperature at which most pathogenic forms grow best, and, moreover, certain forms react upon the gelatin so as to produce liquefaction. To meet these conditions another gelatinous substance of vegetable origin, agar,* which remains solid up to 100° C. and is not liquefied by bacteria, has been found to possess special advantages. Milk, potato, and blood-serum complete the list of the other media in common use.

Beef Broth.—

Chopped lean beef	500 gm. (about 1 lb.)
Distilled water	1000 c.c.
Peptone (Witte's)	10 gm.

The minced beef is placed in the water and kept in the ice-box overnight. It is then strained, and the juice well pressed out and boiled for half an hour to coagulate the albumins. These are next filtered out by the use of filter-paper, the fluid made up to 1000 c.c. with distilled water, and the peptone carefully stirred in and dissolved by heating. The broth, which at this stage is generally quite acid, is then titrated and adjusted while hot to the desired reaction by addition of the required amount of a normal solution of sodium hydroxid.

Titration.—Put 5 c.c. of the medium to be tested and 45 c.c. of distilled water into an evaporating dish. Boil one minute. Add 1 c.c. of phenolphthalein solution (0.5 per cent. in 50 per cent. alcohol). Run into the hot mixture enough $\frac{N}{20}$ NaOH solution to produce a faint but distinct pink color. Read from the buret the amount of $\frac{N}{20}$ NaOH used to neutralize the 5 c.c. and calculate the amount of $\frac{N}{1}$ NaOH necessary to neutralize the entire quantity of broth.

The following example will illustrate the method followed. If the required reaction of the finished medium is "(+ 1)," a symbol used to indicate that 1 per cent. of normal alkali is necessary to bring it to the phenolphthalein neutral point, and the buret reading shows that 1.8 c.c. $\frac{N}{20}$ NaOH

* First used by Frau Hesse.

has been used in neutralizing the 5 c.c. of broth, then the problem takes this simple form:

5 c.c. of broth is neutralized by 1.8 c.c. $\frac{N}{20}$ NaOH

100 c.c. " " " " " 36 c.c. $\frac{N}{20}$ NaOH or 1.8 c.c. $\frac{N}{1}$ NaOH

1000 c.c. " " " " " 18 c.c. $\frac{N}{1}$ NaOH

Since the desired reaction is + 1, which, it may be said, is the "standard reaction,"* the above figures indicate that the broth as titrated is 0.8 per cent. too acid and that 8 c.c. of normal NaOH per liter must be added to obtain the result aimed at.

The broth is then heated † in the autoclave to 120° C., allowed to cool again to bring down the precipitate ‡ caused by change of reaction, filtered, placed in flasks or tubes, and sterilized. Instead of the fresh meat, three grams of a standard meat extract, such as Liebig's, may be used to each 1000 c.c. of water.

Dextrose-free Broth.—Meat, and also extract of meat, often contains a slight amount of muscle sugar or glucose. If sugar-free broth is required, a simple method of removing the muscle sugar is employed (Theobald Smith): Ten to twenty c.c. of a pure, young broth culture of B. coli is added to the infusion of meat,§ and incubated eighteen hours at 37°. The broth is then boiled to kill the organism and the preparation carried on as above. Control tests should always be made, since prolonged activity of B. coli may cause the development of indol or other products. Special broth media are prepared by adding 1 per cent. of dextrose, lactose, saccharose, or other carbohydrates to the sugar-free broth. Broth containing carbohydrate should be sterilized by the discontinuous method.

Gelatin.—Ordinary nutrient gelatin is prepared by adding from 10 to 12 per cent. of "gold label" gelatin (Coignet et Cie, Paris) to broth prepared as above.‖ The medium should be heated only long enough, over a water-bath or an asbestos pad,

* Report of Committee on Standard Methods of Water Analysis of the Amer. Pub. Health Assoc., Jour. Infect. Dis., 1905, Suppl. No. 1, p. 106.

† After heating it is desirable to repeat the titration, as boiling releases free H ions from the phosphates in the medium.

‡ This precipitate is magnesium ammonium phosphate (Jordan: Jour. Infect. Dis., 1905, 2, p. 51).

§ Commercial meat extract should not be used for this purpose.

‖ For detailed methods of preparing large amounts of gelatin and agar see Report of the Committee on Standard Methods of Water Analysis, 1905, p. 108.

to dissolve the gelatin and should be stirred constantly; before filtration the reaction must be readjusted, since the addition of gelatin renders the medium acid. A clear filtrate may be assured by cooling the medium to 60° C. and stirring in slowly the white of an egg dissolved in 30 c.c. water. Or 0.6 per cent. of Merck's dried egg albumin may be used. Gelatin may be autoclaved at 120° C. for five minutes and still solidify if placed at once in the ice-box. In warm weather as much as 12 per cent. of gelatin is necessary. Special care should be taken to prepare gelatin each time in a uniform way, since too great variation in the results of bacterial growth upon it will otherwise be obtained.*

Agar.—To the standard beef broth add 1.5 per cent. or, better, 1.0 per cent. pure thread agar. This medium is somewhat more difficult to prepare than gelatin because of the higher melting-point of the agar and consequent trouble in dissolving and filtering. The difficulty is greatly reduced if the strands of agar are finely cut or chopped and thoroughly dissolved in a minimum quantity of boiling water before the hot broth is added. If the filter-paper and funnel are wet with boiling water, little difficulty will be experienced in filtering while the medium is still hot. Sterilize in the autoclave.

Dextrose and Lactose Litmus Agar.—To agar made with sugar-free broth, 1 per cent. of dextrose or of lactose may be added before sterilization in the Arnold steam-bath at 100° C. Enough sterilized litmus solution † to produce a clear dark color should be added from sterile tubes just before plating or inoculation.

Milk and Litmus Milk.—Milk is a useful medium for determining the production by bacteria of acids or enzymes which precipitate or digest the casein, or act upon the lactose. Fresh milk, or in large cities "certified" milk, should be obtained, steamed for fifteen minutes in the Arnold sterilizer, and placed in the ice-box overnight to allow the cream to separate. The middle portion of the milk should then be siphoned off, avoiding both cream and sediment. The usefulness of milk as a diagnostic culture-medium is enhanced by the addition of litmus.† Fresh milk is naturally neutral or faintly alkaline to litmus. Milk may be sterilized for five minutes

* Whipple: Tech. Quart., 1902, 15, p. 127.

† Use 5 to 8 per cent. of a 1 per cent. solution of Merck's purified litmus extract, or a 1 per cent. solution of Kahlbaum's azolitmin.

at 120° in the autoclave. Many prefer to sterilize milk in the Arnold steamer for three or four successive days.

Blood-serum.—This medium is especially useful for cultivating the diphtheria bacillus, the pneumococcus, and a few other organisms. Beef blood is usually obtained, allowed to clot, and the clear, straw-colored serum pipetted off. Serum may be sterilized in a fluid condition by the discontinuous method at a low temperature (60° for eight days), or be solidified at 76° and remain translucent, or be coagulated and rendered opaque by running it slowly up to 95°. If the temperature is raised rapidly, bubbles are formed which disturb the slanted surface. *Löffler's blood-serum mixture,* ordinarily used for growing B. diphtheriæ, consists of three parts of beef-serum mixed with one part of neutral broth containing 1 per cent. of dextrose.

Potato.—Many non-pathogenic organisms grow readily and characteristically on potato. Of the several methods of preparing potato the simplest is as follows: Cut a cylindric piece of potato 5 cm. long by means of an apple-corer. Halve this by a diagonal cut lengthwise. The pieces should be placed in cold running water for a few hours and then slipped into potato tubes so that they present a slant surface uppermost for inoculation. Special potato tubes are made with a constriction in the glass, which holds the potato about an inch from the bottom. It is well to fill the tube below with distilled water or broth to provide moisture. Sterilize in the autoclave. The following medium, devised by Heinemann,* has been found advantageous as a substitute for potato. Fifteen grams of agar are dissolved by heat in about 600 c.c. of water. A solution of the following salts in 200 c.c. of water is then prepared:

Asparagin	5 gm.
Dipotassium hydrogen phosphate	2 "
Disodium hydrogen phosphate	2 "
Magnesium sulfate	2 "
Calcium chlorid	2 "
Ammonium lactate	2 "

This solution, in which a fine precipitate is formed, is mixed with the hot agar solution, 10 grams of peptone are added, and the whole

* Heinemann: Jour. Infect. Dis., 1907, 4, p. 283.

mixture filtered after the reaction, which is about 5 per cent. acid, is brought to the neutral point with phenolphthalein as an indicator. To the hot filtered solution a suspension of 30 grams of washed potato starch, made perfectly homogeneous in a mortar, is gradually added with constant stirring. The mixture is then brought nearly to the boiling-point and finally weighed. The total should weigh 1000 grams. The medium is tubed and sterilized in the autoclave for five minutes at 120° and is cooled in a slanting position. The salts used in the medium are the principal ones contained in potato according to chemical analysis.

Synthetic Media.—Media whose exact chemical composition is known offer certain advantages for the careful study of bacteria. Environment may thus be reduced to its simplest terms, or varied definitely and at will. Certain bacteria will develop in water which has been redistilled in glass, and has a trace of $MgSO_4$ added. Others refuse to multiply in more complex solutions. One of the simplest synthetic or "non-proteid" media is as follows:*

Redistilled water	1000 c.c.
Asparagin	2 gm.
$MgSO_4$	1 "
K_2HPO_4	1 "

Uschinsky's medium (Fränkel's modification):†

Water	1000 c.c.
Asparagin	4 gm.
Ammonium lactate	6 "
Na_2HPO_4	2 "
NaCl	5 "

Special Media and Biochemical Tests.—A great variety of special media are used in connection with the study of different organisms, either because such media are particularly favorable to the growth of those organisms or because they reveal certain characteristic features and biochemical reactions. The addition of glycerin to nutrient agar, for example, favors the development of the tubercle bacillus. Certain organisms, of which the influenza bacillus is the type, require the presence of hemoglobin in the culture-medium, and are often designated on that account as the hemophilic

* Jordan: Bot. Gaz., 1899, 27, p. 9; Jour. Expt. Med., 1899, 4, p. 627.

† Hyg. Rundsch., 1894, 4, p. 769. For other formulas see Erwin Smith, "Bacteria in Relation to Plant Diseases," Washington, 1905, p. 197.

bacilli.* A few media have a decisive differential value; the typhoid bacillus does not produce either gas or acid in lactose broth, whereas a closely allied bacillus, B. coli, found in the normal human intestine, actively ferments lactose. In general the ability to ferment carbohydrates or substances like mannite and glycerin which are added to the ordinary sugar-free culture-media, constitutes one of the most important differential characters of bacteria.

The *reducing power* of bacteria may be measured by the loss of color of litmus (*e. g.*, in litmus milk) or of methylene-blue, or by the reduction of nitrates to nitrites. The reduction of nitrates may be determined in the following way. After four days' incubation at 37° C. in nitrate broth (0.1 per cent. peptone, 0.02 per cent. nitrite-free potassium nitrate) add to 3 c.c. of the culture in a clean test-tube 2 c.c. each of the following solutions: (1) Sulphanilic acid solution made by dissolving eight grams of the purest sulphanilic acid in 1000 c.c. of 5N acetic acid (sp. gr. 1.041); (2) α-amidonaphthalene acetate solution prepared by dissolving 5.0 grams solid α-naphthylamine in 1000 c.c. of 5N acetic acid and filtering the solution through absorbent cotton. The development of a rose color indicates the presence of nitrites. An uninoculated tube of the medium should always be treated in the same way for a control. Nitrate solution may also be inoculated in the fermentation tube, where the evolution of gas indicates a still further reduction to free nitrogen gas.

The production of *indol* may be advantageously determined in Dunham's peptone solution (1 per cent. peptone and 0.5 per cent. NaCl in water). After four days' incubation at 37° add two drops of concentrated sulfuric acid and 1 c.c. of a 0.01 per cent. solution of sodium nitrite and allow to stand for half an hour, or warm slightly. The appearance of a pink color indicates the presence of indol.

The Fermentation Tube.—As already pointed out, various forms of bacteria differ greatly in their ability to ferment carbohydrate substances. The use of special tubes for studying fermentation and gas-production was first recommended by Theobald Smith,† and has been generally adopted in this country. The tubes are

* See Davis: Jour. Infect. Dis., 1907, 4, p. 73.

† Smith, Theobald: "The Fermentation Tube," Wilder Quarter Century Book, Ithaca, 1893, p. 212.

filled with broth from which the muscle-sugar has been removed and to which a definite amount, usually 1 to 2 per cent., of some carbohydrate has been added. The growth of a gas-forming organism leads to the collection of gas in the closed arm, the displaced broth being forced out into the bulb. The amount of gas is measured in terms of percentage of the length of the closed arm, most conveniently by Frost's gasometer card (Fig. 6). At the end of

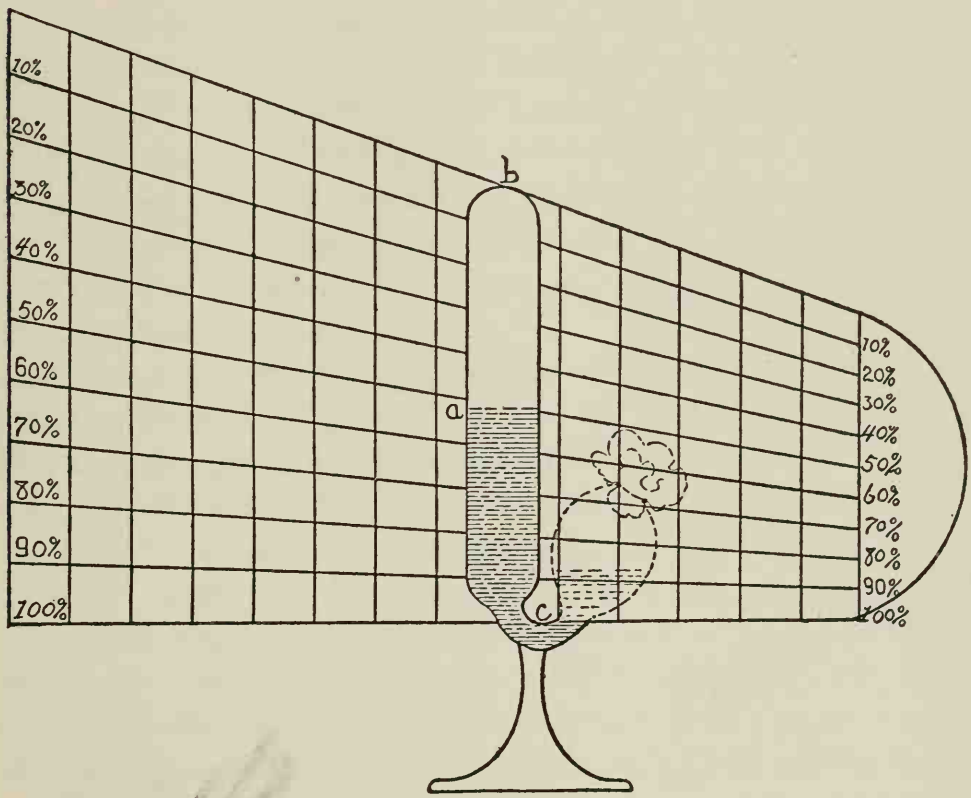


Fig. 6.—Frost's chart for measuring gas in the fermentation tests (Heinemann's "Laboratory Guide").

forty-eight hours the gas may be roughly analyzed in the following way: After the total quantity of gas is measured, the bulb is filled with a 2 per cent. NaOH solution and the mouth of the tube closed tightly with the thumb. The gas is tilted back and forth between the bulb and the closed arm several times and finally allowed to collect in the closed arm. When the thumb is released the fluid rises in the arm, due to the fact that the sodium hydrate has absorbed the carbon dioxid; the residual gas, which is usually chiefly hydrogen, can then be measured. The ratio of hydrogen to carbon dioxid or

the *gas formula* of an organism may be stated, for example, as follows:

$$H : CO_2 :: 30 : 15 :: 2 : 1.$$

A modification of the ordinary fermentation tube, devised by Hill, has the long arm closed by a tightly fitting ground-glass stopper (Fig. 7). This permits the examination of the contents of the arm, either chemically or bacteriologically, without contamination by or interference with the fluid in the bulb.

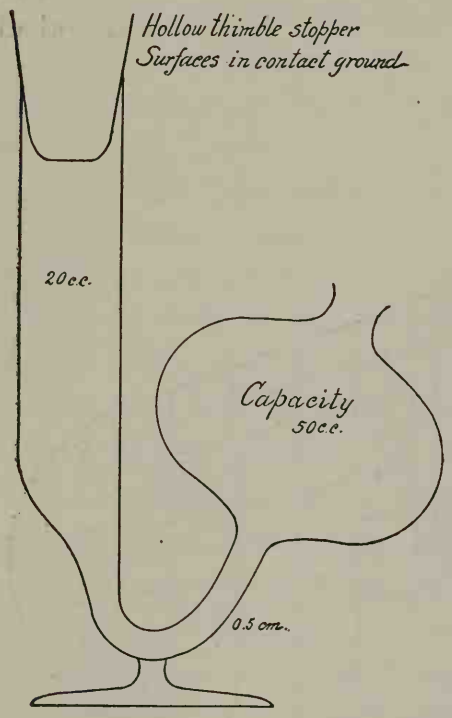


Fig. 7.—The Hill fermentation tube (Gorham).

Thermal Death-point; Disinfectants.—The importance of knowing the condition and the time necessary for the destruction of bacteria has caused the introduction of certain exact methods for testing the death-point of various organisms subjected to the influence of heat and to the action of disinfectants. The heating test is best made by use of a small glass bulb devised by Sternberg (Fig. 8). To fill the tube, warm the bulb slightly to drive out the air and then insert the stem at once into the bacterial suspension, which is drawn by suction into the bulb as it cools. The neck is then sealed in the flame. An ordinary thin glass test-tube may be used if drawn out in the glass flame to form a narrow neck in the middle, through which a definite amount of culture may be run into the bottom of the tube. The neck is then drawn out in the flame and sealed off. Heating should be done with the bulbs completely immersed in a water bath and held suspended by a wire away from the bottom frame. It is advisable to begin at a temperature of 50° C. for five minutes and

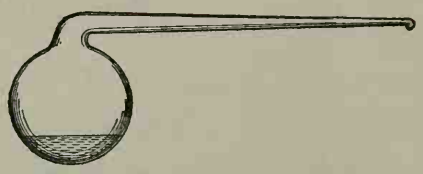


Fig. 8.—Sternberg's bulb for testing thermal death-point.

for ten minutes, repeating for every two degrees up to 70°. Spores require still higher temperatures for their destruction. After being cooled quickly the bulb contents are emptied into a Petri dish and melted agar added, to determine by the development of colonies the number of live organisms present. Eijkman* has called attention to an important error in such experiments. Many cells are so damaged by exposure to heat (and probably the same is true of other disinfecting agents) that they develop exceedingly slowly, although their vitality is not destroyed. In one experiment with Bacillus coli no colonies were visible on a gelatin plate within three days after incubation of the heated culture, but on the same plate after fifteen days 670,000 colonies could be enumerated. In order to discover whether all the organisms have been killed the contents of the bulb should be emptied, preferably into a fluid medium composed of equal parts of litmus milk and broth (Harris).

The strength of a disinfectant is usually determined by its effect upon pure cultures of bacteria. Koch tested the action of disinfectants on anthrax spores by placing in the disinfectant solution silk threads which had been dipped in an emulsion of the spores and dried. The threads were then washed and laid upon the surface of agar. Hill † has devised a simpler and more exact method of preparing test objects for disinfectants which is now widely used. Sterilized glass rods are dipped to a depth of one inch into forty-eight-hour-old broth cultures of the organism to be used in the test. The rods are then placed in test-tubes fitted with cotton plugs, carefully dried in the thermostat, and immersed in the disinfectant solution for accurately timed periods, varied as desired. Each rod on removal is gently but thoroughly washed with sterile physiologic salt solution, then placed in a tube of sterile broth, and incubated at 37° C.

Sterilization by Filtration.—It is often found desirable to sterilize water and other fluids, such as culture-media in which bacteria have been growing, without subjecting them to heat or to the action of disinfectants. The method of sterilization by filtration is especially used in obtaining soluble bacterial products, such

* Eijkman: Centralbl. f. Bakt., II, 1909, 22, p. 508.

† Rep. and Papers, Amer. Public Health Assoc., 1898, 24, p. 264.

as toxins and enzymes, which might be injured by chemicals or heat. The bacterial products are separated from the bacteria by filtration of the culture through unglazed porcelain cylinders, which, together with the glass and rubber connections forming part of the filtration apparatus, have been previously sterilized by autoclaving. The porcelain cylinders in use for this purpose vary in form and in the size of their pores, one of the most commonly used being the "Chamberland B. pattern." The passage of fluids is usually very slow through the most compact cylinders, and may be hastened by a water suction-pump. An overflow bottle should be interposed between the filter and the tap to prevent any back-flow of water from entering the filter flask (Fig. 9). A very useful form of apparatus for filtering such fluids as blood serum under pressure is shown in Fig. 10. The small Berkefeld filter with cylinders made

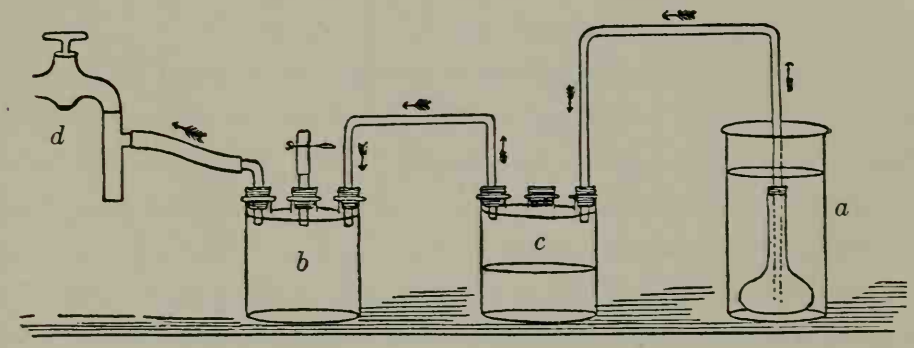


Fig. 9.—Apparatus for the rapid filtration of toxins, etc.: *a*, Filter flask ; *b*, Woulfe bottle to guard against regurgitation of water from the pump ; *c*, reservoir for the filtrate ; *d*, water vacuum pump (McFarland).

of infusorial earth is most convenient for obtaining clear solutions, but the coarser grades of Berkefeld filters permit the passage of very small bacteria. Minute defects in the cylinders sometimes occur, and the filtrate should be tested for sterility by inoculation of a small amount into culture-media. Bacterial fluids after filtration should be protected from light and kept in the ice-box.

Methods of Obtaining Pure Cultures.—When fluid culture-media are inoculated with such substances as soil or water, many kinds of organisms develop simultaneously side by side, and a heterogeneous mixture of bacteria results. Koch * was the first

* Koch: Mitth. a. d. kais. Gesundh., 1881, 1, p. 1.

to devise a method of using solid media which permitted the separation of one kind of bacterium from another. If nutrient gelatin and agar are inoculated while fluid (for example, at 42° C.), and are then solidified and kept under favorable temperature conditions, many of the living bacteria that have been introdeced are able to multiply. Since the bacteria cannot move about freely, but are fixed in the stiffened medium, the progeny of each germ forms distinct masses or colonies. If the colonies are not closely crowded, a pure culture, that is to say, the descendants of a single germ, may be obtained by touching a colony with the tip of a sterile platinum needle (a process technically known as "fishing") and inoculating tubes of fresh culture-media. In order to secure a large surface upon which the colonies shall be spread out and made easily accessible, the gelatin or agar, after inoculation, is poured while still fluid into sterilized flat shallow dishes (Petri dishes) fitted with glass covers. Porous tile covers which allow ventilation are sometimes used, especially when the number of colonies is to be counted, since glass covers often cause condensation of moisture on the surface of the medium and consequent running together of the colonies.*

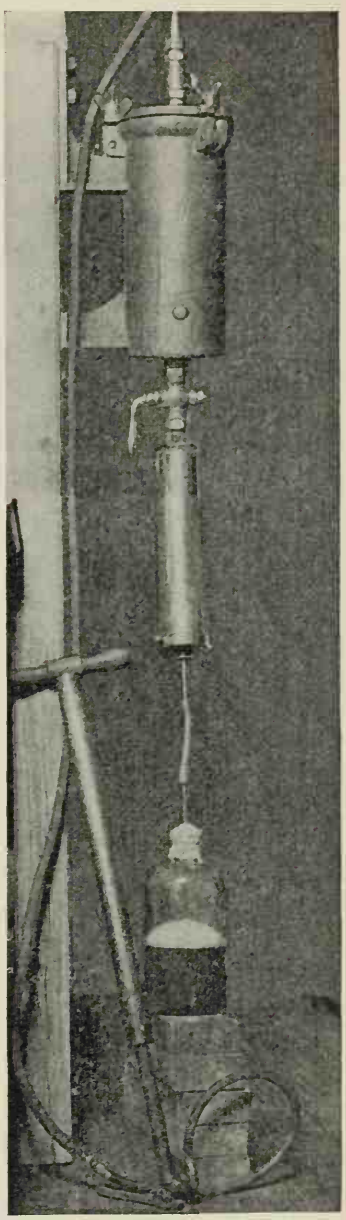


Fig. 10.—Pressure filter (Heinemann).

Technic of Making Plate Cultures.—Three tubes of agar (1, 2, and 3), melted at 100° C., are placed in a water-bath at 42° C., a temperature that is just above the solidifying point of agar and is not injurious to bacteria. It is often desirable to make first a suspension in salt solution, as, for example, in dealing with material like

* Hill: Jour. Med. Res., 1904, 13, p. 93.

pus. Tube 1 is inoculated with a platinum loopful of the material to be plated. The cotton plug is then replaced and the contents of the tube mixed by carefully tilting back and forth and rotating the tube on its long axis. From this tube two loopfuls of agar are transferred to tube 2, and after mixing, two more loopfuls carried from tube 2 to tube 3. The contents of the several tubes are then poured into Petri dishes. As soon as the cotton plug is removed, the mouth of each tube should be passed through the flame, inserted under the edge of the lifted Petri dish cover, and the agar quickly poured out. The covered Petri dish may then be tipped cautiously back and forth to distribute the agar evenly before it solidifies. If there are a great many bacteria in the original material, the plate from tube 3 will probably contain the organisms in small enough numbers to develop well-isolated colonies. On the other hand, if there are very few bacteria in the material inoculated, plate 1 will probably present more satisfactory conditions. Gelatin plates are made in the same manner as agar except that gelatin may be cooled as low as 25° C. without solidifying.

Dilution.—It is sometimes of advantage before plating to make accurate dilutions of highly polluted fluids, such as sewage, in order to get colonies few enough in number to be well isolated. If there is reason to suppose that the number of bacteria is more than 200 per c.c., 1 c.c. of the sample is mixed with 9 c.c. of sterile water. If a higher dilution is required, proceed in a similar manner.

(A) To dilute	1 : 10	use 1 c.c. of sample to	9 c.c. of sterile water.							
(B) " "	1 : 100	" " "	" " 99	"	"	"	"			
(C) " "	1 : 1,000	" " "	(A) " 99	"	"	"	"			
(D) " "	1 : 10,000	" " "	(B) " 99	"	"	"	"			
(E) " "	1 : 100,000	" " "	(C) " 99	"	"	"	"			
(F) " "	1 : 1,000,000	" " "	(D) " 99	"	"	"	"			

Separation of Bacterial Species by Heat.—Spore-forming organisms are sometimes separated from other bacteria by heating mixed cultures containing spores to 80° C. for fifteen minutes. This procedure kills off any vegetative forms that may be present, but leaves the heat-resistant spores able to develop if placed under favorable conditions. A further separation of different varieties of spore-forming organisms must then be effected by plating or animal inoculation.

Separation by Animal Inoculation. — Certain pathogenic bacteria that in the animal body often occur mixed with other species, as is the case, for example, with B. tuberculosis or B. tetani, are sometimes obtained free from other bacteria by inoculating an animal with the material containing the mixture of organisms. After allowing time for the bacteria to develop, the animal is killed, and tubes of suitable media are inoculated from the characteristic lesions; in such cases the specific bacillus will often be found in pure culture in the tissues.

Method of Growing Anaërobes.—A number of devices have been used for the cultivation of certain organisms known as anaërobes (p. 73), which will not grow in the presence of free oxygen. Pasteur spread a layer of oil over the surface of media in order to

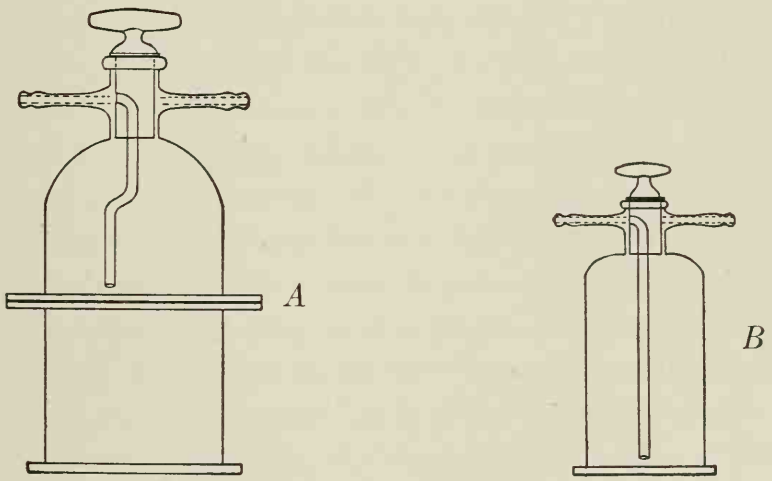


Fig. 11.—*A*, Novy jar for plate cultivations; *B*, Novy's jar for tube cultivations (Eyre).

shut off the air. Koch grew anaërobes on agar or gelatin plates under a piece of sterile mica. Liborius employed the method of inoculation deep into solid media, a simple method still in use. A "shake culture" in glucose agar may be made by previously boiling the agar for fifteen to twenty minutes to drive off the absorbed air, then cooling quickly to 42° C., and inoculating. The tubes of agar are then solidified at once in cold water and incubated; under these conditions anaërobic organisms often develop well in the depths of the agar.

Hydrogen Method.—Success is still more certain if the tubes are

placed in a Novy anaërobic jar (Fig. 11). The air in the jar is replaced by hydrogen by allowing a full stream of washed hydrogen from a Kipp generator to pass through for ten to fifteen minutes before closing the stop-cock. The Novy jar is especially useful for making anaërobic plate cultures.

Absorption of Oxygen.—Any vessel with a tight cover, such as a Novy jar, an ordinary chemical desiccator, or a Mason fruit-jar, may be used for Buchner's pyrogallic acid method. The principle of this method is the absorption of oxygen. Dry pyrogallic acid (10 grams per liter of air-space) is placed in the bottom of the jar, 150 c.c. of a 1 per cent. solution of NaOH poured on the pyrogallic acid, the cultures put in place, and the jar closed at once. This method may also be used directly in culture-tubes, a stopper of absorbent cotton being pushed down to leave an inch space at the top of the tube, pyrogallic acid and NaOH solution placed in this space, saturating the cotton, and the tube closed at once with a tight-fitting rubber stopper.*

Vacuum Method.—An unpublished method first used by Gwyn in combination with the pyrogallic acid method has been found practicable by itself. The cultures are placed in a desiccator jar which has a cover with a single stop-cock. A piece of filter-paper saturated with alcohol is put into the jar, a lighted match applied, and the vaselined cover, with stop-cock closed, placed quickly in position. A good vacuum is formed, and if care be taken that the paper is well saturated with alcohol, no deleterious gaseous products of combustion are formed. It is necessary to open the cock before the cover can be removed. This is a simple and ready method if cultures are being made and examined often. Wright† and Smith‡ have suggested good and simple methods of anaërobic culture in fluid media. Important points to observe in working with anaërobes are: (1) The culture-media should be freshly prepared. (2) The medium employed, whether gelatin, agar, or broth, should contain 1 per cent. glucose and should be freshly boiled and cooled before using. (3) The reaction of the medium should be nearly neutral to phenolphthalein.

* Wright: Jour. Bost. Soc. Med. Sci., 1900, 5, p. 114.

† Wright: Ibid., 4, p. 119.

‡ Smith: Ibid., 1899, 3, p. 315.

Animal Inoculation.—Animal inoculations may be made for various reasons: (1) To obtain pure cultures of an organism from infected material. (2) To determine the virulence of an organism which is under study or to observe the changes that it evokes in the animal body. The animals most used for laboratory purposes are guinea-pigs, rabbits, white mice, and white rats. (3) For continuing the life of an organism that does not grow except in the animal body (for example, the virus of hydrophobia and smallpox).

Guinea-pigs and rabbits are usually inoculated subcutaneously or intraperitoneally. Subcutaneous inoculation is generally made under the skin of the abdomen by means of a hypodermic needle. Pus or similar material may be suspended in sterile physiologic salt solution. The animal is conveniently held by an assistant, who turns its abdomen upward. The hair about the proposed site of inoculation should be clipped close. The site of inoculation is then rubbed with cotton soaked in 1:1000 HgCl or in 95 per cent. alcohol. Make the puncture behind and to one side of the umbilicus, and if a large quantity of fluid is to be injected, run the needle carefully forward its full length through the subcutaneous tissue. An egg-shaped swelling of the skin will form about the point of the needle as the syringe is emptied; when the needle is withdrawn, apply a drop of collodion to close the wound. "Pocket" inoculations are carried out by making a small incision in the skin, and separating the skin from the muscles by pushing in sterile scissors, which are then slightly expanded, closed again, and removed; a piece of tissue may then be inserted and the wound closed with collodion or with one or two sutures.

Intraperitoneal inoculation is made in essentially the same manner as subcutaneous, passing the needle first beneath the skin, then holding it at about a right angle to the peritoneal wall, and carefully thrusting it through, taking care not to penetrate the intestines. Rabbits may also be inoculated intravenously in the marginal vein of the ear. Rabbits are convenient animals to use in experiments where the blood is to be tested after inoculation, because of the readiness with which blood may be obtained from the large veins of the ears.

Mice are usually inoculated subcutaneously on the back at the

root of the tail. A small wire cylinder mouse-holder aids in manipulation.

Microscopic Methods.—*Examination of Living Bacteria.*—In order to determine form, motility, spore formation, and reaction with specific serum, it is often necessary to study bacteria alive. The hanging-drop method is commonly used for this purpose.

A special slide has been devised for the hanging drop which has a circular pit ground into the glass on one side. When bacteria are growing in fluid media, a drop may be transferred with the platinum loop to the center of a cover-slip which has been sterilized by flaming, and the cover-glass then inverted over the hollow chamber with the drop depending freely downward. If the bacteria are removed from solid media, they should be suitably mixed with sterile physiologic salt solution and a drop of the suspension placed on the cover-slip. The hollow chamber is sealed by cedar oil smeared on the edge, so that the drop is not disturbed by air-currents and does not evaporate rapidly.

Extreme care must be taken in focusing upon the hanging drop, as unstained organisms are very difficult to see. The diaphragm of the microscope should be adjusted to a small aperture in order to take advantage of the lights and shadows caused by the difference in light transmission of the bacterial bodies. The edge of the hanging drop should first be found with a low-power lens and exactly centered, and then the high power turned in place and cautiously brought into focus.

The so-called *hanging block* for studying the development of bacteria was invented by Hill,* and consists of a thin slice of nutrient agar (or of gelatin if a warm chamber is not necessary) which is seeded on its surface with a number of organisms and then inverted on a cover-glass and fastened by searing its edges with a hot needle. The cover-slip should be sealed over a moist chamber with paraffin. The organisms are thus held in one position on the solid medium, and the mode of cell division can be advantageously followed.

Young, vigorous cultures not more than twenty-four hours old should be used for studying cell division and also for determining motility in the hanging drop.

* Hill: Jour. Med. Res., 1902, 7, p. 202.

Examination of Stained Bacteria.—Film Preparation: Cover-slips and slides for making stained preparations should be thoroughly clean and sterile. If new, they should be washed in soapsuds or NaOH solution, boiled in potassium dichromate cleaning fluid, rinsed well in distilled water, and stored in 95 per cent. alcohol or in alcohol and ammonia. They are then ready for use, and need only be dried with a clean soft linen cloth and freed from grease by passing them two or three times through the Bunsen flame. The cover-slip may be conveniently manipulated by means of special cover-slip forceps (Fig. 12).

Fresh young cultures twenty-four to forty-eight hours old grown on agar are usually the best for ordinary stained prepar-

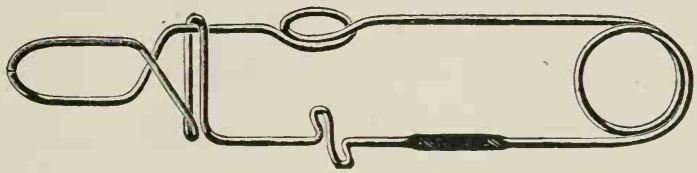


Fig. 12.—Novy's cover-glass forceps.

ations. A loop of filtered water is placed on a cover-glass or slide, and a small amount of bacterial growth mixed with this and spread evenly over the surface. If the glass is not clean, the mixture will gather in droplets instead of spreading in an even film. This film is then allowed to dry in the air, and when well dried the preparation is passed three times slowly through the Bunsen flame, film side up, to fix the film. Fixing may be accomplished also by means of absolute alcohol or glacial acetic acid, which must be washed off before the next step. The fixed film is covered with the stain, allowed to stand fifteen to thirty seconds, washed thoroughly with clean water, and mounted in water for examination; if desired, it can be dried later and mounted permanently in balsam.

The basic anilin dyes most commonly used for staining bacteria are, in order of merit, gentian-violet, methylene-blue, and fuchsin. Saturated solutions of these stains in 95 per cent. alcohol should be kept in stock, so that for immediate use it is only necessary to filter a little of the alcoholic solution into ten times its bulk of distilled water. Except in special cases (tubercle bacillus, spores,

etc.), bacterial films stain very quickly with fuchsin or with gentian-violet. The action of methylene-blue may be hastened by gentle heating; some organisms, like the bacilli of glanders and of typhoid fever, take up a stain slowly and are best colored by the more intense stains. Methylene-blue is especially satisfactory for examining fluids from the body (blood, pus, etc.). The staining power of solutions may be increased by heating, by the use of substances which act as mordants, by prolonging the staining process, and by the addition of alkalis. Some of these special methods and stains are as follows:

*Löffler's Methylene-blue:**

Sat. sol. methylene-blue in alcohol..... 30 c.c.
Sol. KOH in distilled water (1 : 10,000).....100 "

Anilin Gentian-violet:

(*a*) Anilin oil water is made by adding 2 c.c. anilin to 98 c.c. distilled water; shake violently. Filter several times through filter-paper.

(*b*) Anilin oil water.....75 parts
Sat. sol. gentian-violet in alcohol.....25 "

Gram's Method:† Certain organisms, when stained and afterward treated with a solution of iodin and washed in 95 per cent. alcohol, give up the stain; others retain the color when subjected to this process. These latter organisms, examples of which are the anthrax bacillus and the pneumococcus, are said to be "gram-positive," or to "stain by Gram's method." Those losing the stain are "gram-negative." This method affords a means of measuring the relative permeability of micro-organisms to soluble substances. The gram-positive bacteria are those in which the iodin gentian-violet combination penetrates more or less deeply into the interior of the cell; the gram-negative varieties are only superficially affected.‡

1. Stain in anilin gentian-violet for one and one-half minutes.
2. Wash in water.
3. Treat with Gram's solution (iodin, 1 part; potassium iodid, 2 parts; water, 300 parts) until purplish black, one and one-half minutes.

* Mitt. a. d. kais. Gesundh., 1884, 2, p. 421.

† Fortschr. d. Med., 1884, 2, p. 185.

‡ Brudny: Centralbl. f. Bakt., II, 1908, p. 62.

4. Decolorize with 95 per cent. alcohol for at least five minutes, wash, dry, and mount.

A contrast stain with fuchsin or 0.5 per cent. solution of safranin may be made if desired (for example, in examining gonorrheal pus); twenty-four-hour agar cultures should be used. For sections, prolong the process. Modifications, Weigert,* Nicolle.†

Stain for Tubercle Bacilli and Other "Acid-proof" Bacilli: Tubercle bacilli require a powerful stain containing a mordant, and with this aid stain only with difficulty; when once stained, however, they resist decolorizing with equal tenacity. The following method is most commonly used:

Ziehl-Neelsen Carbol-fuchsin Stain:‡

Basic fuchsin	1 part
Absolute alcohol	10 parts
5 per cent. sol. carbolic acid	100 "

1. Flood the cover-glass with carbol-fuchsin and heat gently over the flame until the film seems deeply stained.

2. Wash and decolorize with a 2 per cent. solution of hydrochloric acid in 80 to 95 per cent. alcohol. It is well to decolorize until the thinner portions of the film show no red color.

3. Wash in water.

4. For a contrast stain use methylene-blue.

5. Wash and examine.

Möller's Spore Stain:§ Like the tubercle bacillus, bacterial spores are resistant to staining and to decolorizing. The method of treating them is as follows:

1. Prepare films from a twenty-four-hour agar culture.

2. Place in chloroform for two minutes.

3. After drying in the air, cover with a 5 per cent. solution of chromic acid for two minutes.

4. Wash thoroughly in water.

5. Cover with carbol-fuchsin, and heat for five minutes over the water-bath at 100°, or over a small flame, simmering gently.

* Fortschr. d. Med., 1887, 5, p. 228.

† Ann. de l'Inst. Past., 1895, 9, p. 666.

‡ Deut. med. Wochenschr., 1882, 8, p. 451; also Med. Centralbl., 1883, 21, p. 500.

§ Centralbl. f. Bakt., 1891, 10, p. 273.

6. Decolorize with 1 per cent. sulfuric acid for twenty-five to thirty seconds.

7. Wash thoroughly in water.

8. Mount in water and examine under the microscope to see if the spores are cherry-red and the protoplasm colorless or faintly pink.

9. Counterstain with methylene-blue for ten to fifteen seconds without heat.

10. Wash, examine in water, and mount in balsam.

The body of the cell should appear blue; the spore, red.

Capsule Stain: Welch's method* is used for staining encapsulated organisms.

1. Cover the film with glacial acetic acid.

2. Draw off acetic acid and treat the film several times with anilin gentian-violet.

3. Wash in 0.85 per cent. NaCl solution and examine in the same solution. Avoid the use of water at any stage. The capsule appears as a pale violet halo around the deeply stained bacterium.

Flagella Stain: For staining the flagella of bacteria, young agar cultures of twelve to eighteen hours should be used. Care must be taken to treat the organisms gently, since under some conditions the flagella are easily broken off. A tube containing 5 c.c. of sterile water is carefully inoculated with enough of the culture to produce a faint turbidity. The tube is then placed in the thermostat for an hour to allow clumps to sediment and to permit slight development. Two or three loopfuls of this suspension are then placed upon a cover-slip *without spreading*, dried at 37°, and fixed.

Löffler's stain,† in which a mordant is used, gives good results.

1. Cover the film with the mordant:

Tannic acid (25 per cent. aqueous solution)	10 parts
Ferrous sulfate (saturated aqueous solution)	5 "
Fuchsin (saturated alcoholic solution)	1 part

2. Heat over a water-bath for five minutes; keep the cover-slip flooded with the mordant.

3. Wash thoroughly in water and dry with filter-paper.

* Bull. Johns Hopkins Hosp., 1892, 3, p. 128.

† Centralbl. f. Bakt. 1889, 6, p. 209; 1890, 7, p. 625.

4. Cover the film with anilin gentian-violet or carbol-fuchsin and heat as before.

5. After washing thoroughly in water the film is ready to be mounted and examined.

In *Van Ermengem's method** three solutions are necessary, as follows:

Solution A—

Osmic acid, 2 per cent. sol.	1 part
Tannin, 10 to 25 per cent. sol.	2 parts

Place the films in this for one hour at room temperature or heat over water-bath at 100° for five minutes. Wash with water, then with absolute alcohol, then with water, and treat with

Solution B—

0.5 per cent. sol. of $AgNO_3$ in distilled water.

Allow films to be in this a few seconds; then, without washing, transfer to

Solution C—

Gallic acid	5 grms.
Tannin	3 "
Fused potassium acetate	10 "
Distilled water	350 c.c.

Keep in this for a few seconds. Then treat again with solution B till the film begins to turn black. Wash and examine.

For other methods see Zettnow,† Pitfield,‡ Williams.§

Romanowsky Stain: This stain, depending upon a combination of eosin with altered methylene-blue, is extensively used in studying protozoan parasites.

Solution A‖—

Methylene-blue (medicinally pure)	2 grms.
Sodium bicarbonate	9 "
Distilled water	25–30 c.c.

Mix the dry ingredients and gradually add the water. Cover and steam in the Arnold sterilizer one and one-quarter hours. Wash the

* Centralbl. f. Bakt., 1894, 15, p. 969.

† Ztschr. f. Hyg., 1899, 30, p. 95.

‡ Med. News, 1895, 67, p. 268.

§ Mallory and Wright: "Pathological Technique," Phila., 1904, p. 105.

‖ After Harris, Bull. Johns Hopkins Hosp., 1907, 18, p. 281. For fuller details see MacNeal, Jour. Infect. Dis., 1906, 3, p. 412.

residue with water, to remove the sodium bicarbonate, add 10 c.c. of 4 per cent. solution of NaOH, and shake. Extract with chloroform and evaporate over a water-bath. Finally, place the dry mass in a bottle and add gradually about 150 c.c. methyl alcohol. This constitutes the stock solution of crude methylene-violet and azure.

Solution B—

Saturated solution of Grübler's watery yellow eosin in methyl alcohol.

To make the dye:

Solution A	66 c.c.
Methyl alcohol	33 "
Solution B	1–1.5 "
Methylene-blue	0.05–0.15 grms.

Place the dye on the cover-slip and allow it to stand one minute. Add, drop by drop, a quantity of water equal to the bulk of the dye, and allow this to stand five minutes. Wash one-half minute in running water.

*Neisser's Method for Diphtheria Bacilli:** Use bacilli grown eighteen hours on Löffler's blood-serum mixture (p. 32) at a temperature of 34° to 36° C.

Stain—

Grübler's methylene-blue	1 grm.
96 per cent. alcohol	20 c.c.
Distilled water	950 "
Glacial acetic acid	50 "

1. Stain one to three seconds.
2. Wash.
3. Stain in Bismarck-brown (2 grms., 1000 c.c. boiling water) three to five seconds.
4. Wash and examine.

The protoplasm is stained a faint brown, the granules are blue.

Study of Pathologic Material.—The examination of material such as pus, blood, or discharges from diseased tissues or organs may be carried out as follows: (1) Gelatin and agar tubes should be inoculated and plates poured at once. If there is reason to suspect that bacteria may be present that cannot develop on the ordinary media, blood-serum or agar smeared with blood should also be inoculated. (2) Several cover-glass preparations should be made at the

* Neisser: Ztschr. f. Hyg., 1897, 24, p. 443.

same time, one to be stained with methylene-blue, one with Ziehl-Neelsen carbol-fuchsin, and one by Gram's method. (3) A guinea-pig or rabbit should be inoculated with a small amount of the material.

The colonies that appear on the plates should be carefully examined, and pure cultures on agar or blood-serum made from any that present characteristic appearances, or that differ materially from one another. If the inoculated animal succumbs, cultures should be made from the site of inoculation, from the heart, spleen, liver, and peritoneal cavity. When no apparent effect follows inoculation, the animal should be killed after five or six weeks, the organs carefully scrutinized for possible tuberculous or other lesions, and cultures made as above.

Study of Pure Cultures.—In order to determine the natural relationship or systematic position of a bacterium it is necessary to observe in pure culture the morphology, staining reactions, mode of growth on various media, the biochemical reactions produced by its development, and in some cases the effect upon animals.

1. *Morphologic Appearance.*—Young twenty-four-hour-old agar cultures should be examined in a hanging drop for motility, form, and size. The hanging block may be used for further observations on size, cell division, grouping, and spore formation. Preparations of both young and old cultures should be stained first by the ordinary dyes, then by special methods, for the purpose of determining the Gram stain reaction, the number and arrangement of flagella and spores, and the absence or presence of capsules.

2. *Cultural Characteristics.*—Cultures freshly isolated from water, soil, or air, or those which have been kept for long periods upon artificial media, are sometimes put through a process of "rejuvenation" before study in order that they may regain lost qualities. This process consists in successive transplantations upon a series of media, *i. e.*, from agar to broth for three days' incubation at 20° C., then to a gelatin plate for the same interval, and finally back to agar, from which the conventional media are inoculated.* Observations of cultural features should cover a period of at least ten days. The colonies on gelatin, and less often on agar plates, sometimes show important differences in form, rapidity of development, elevation, character of periphery, and internal structure as seen

* Fuller and Johnson: Jour. Exper. Med., 1899, 4, p. 310.

under a low-power lens. Agar and potato streak cultures should be examined with reference to form, amount and consistency of growth, elevation, character of surface, edge, and pigmentation or discoloration of the medium. In growth resulting upon blood-serum the same features are to be noted, and also the occurrence of liquefaction or digestion. Gelatin stab cultures often give a characteristic development along the line of puncture; observations should also be made on the character of the surface growth and the progress of liquefaction if present. The production of a surface pellicle, of turbidity and sediment in broth, and the occurrence of coagulation, digestion, and nature of reaction in milk are the features of growth in liquid media that differ with different species. An important biochemical property is the power of fermentation of dextrose, lactose, and saccharose, and in case of gas-production, the amount of gas produced, and the ratio of H to CO_2. Growth in the closed arm of the fermentation tube gives an indication of facultative or obligatory anaërobiosis. It is sometimes considered useful to determine also whether a micro-organism possesses the ability to reduce nitrates in nitrate broth, and to form indol in peptone solution. The virulence of the organism itself and the toxicity of its products of growth (in the form of culture-filtrates) for ordinary laboratory animals completes the usual list of data necessary for classification.

It is of the utmost importance that descriptions be comparative; therefore, in order to prevent confusion of methods and of terms, a committee of the Society of American Bacteriologists on Methods of Identification of Bacterial Species has drawn up a set of rules and of descriptive terms, together with a numerical system of recording salient characters of an organism. The chart devised by this committee is herewith appended.

Source.....Date of Isolation.....Name.....

DETAILED FEATURES.

NOTE—Underscore required terms. Observe notes and glossary of terms on opposite side of card.

I. MORPHOLOGY (2)

1. **Vegetative Cells,** Medium used.....
   temp.....age.....days
   Form, *round, short rods, long rods, short chains, long chains, filaments, commas, short spirals, long spirals, clostridium, cuneate, clavate, curved.*
   Limits of Size.....
   Size of Majority.....
   Ends, *rounded, truncate, concave.*

   Agar Hanging-Block:
   - Orientation (grouping).....
   - Chains (No. of elements).....
   - *Short chains, long chains*
   - Orientation of chains, *parallel, irregular.*

2. **Sporangia,** medium used.....temp.....
   age.....days
   Form, *elliptical, short rods, spindled, clavate, drumsticks.*
   Limits of Size.....Size of Majority.....

   Agar Hanging-Block:
   - Orientation (grouping).....
   - Chains (No. of elements).....
   - Orientation of Chains, *parallel, irregular.*

   Location of Endospores, *central, polar.*
3. **Endospores.**
   Form, *round, elliptical, elongated.*
   Limits of Size.....
   Size of Majority.....
   Wall, *thick, thin.*
   Sporangium wall, *adherent, not adherent.*
   Germination, *equatorial, oblique, polar, bipolar, by stretching.*
4. **Flagella,** No.....Attachment *polar, bipolar, peritrichiate.* How Stained.....
5. **Capsules,** present on.....
6. **Zoogloœa,** Pseudozoogloœa.
7. **Involution Forms,** on.....in....days at....°C.
8. **Staining Reactions.**
   1 : 10 watery fuchsin, gentian-violet, carbol-fuchsin, Loeffler's alkaline methylene-blue.
   Special Stains
   Gram.....Glycogen.....
   Fat.....Acid-fast.....
   Neisser.....

II. CULTURAL FEATURES (3)

1. **Agar Stroke.**
   Growth, *invisible, scanty, moderate, abundant.*
   Form of growth, *filiform, echinulate, beaded, spreading, plumose, arborescent, rhizoid.*
   Elevation of growth, *flat, effuse, raised, convex.*
   Lustre, *glistening, dull, cretaceous.*
   Topography, *smooth, contoured, rugose, verrucose.*
   Optical Characters, *opaque, translucent, opalescent, iridescent.*
   Chromogenesis (8).....
   Odor, *absent, decided, resembling.....*
   Consistency, *slimy, butyrous, viscid, membranous, coriaceous, brittle.*
   Medium *grayed, browned, reddened, blued, greened.*
2. **Potato.**
   Growth *scanty, moderate, abundant, transient, persistent.*
   Form of growth, *filiform, echinulate, beaded, spreading, plumose, arborescent, rhizoid.*
   Elevation of growth, *flat, effuse, raised, convex.*
   Lustre, *glistening, dull, cretaceous.*
   Topography, *smooth, contoured, rugose, verrucose.*
   Chromogenesis (8).....Pigment in water *insoluble, soluble;* other solvents.....
   Odor, *absent, decided, resembling.....*
   Consistency, *slimy, butyrous, viscid, membranous, coriaceous, brittle.*
   Medium *grayed, browned, reddened, blued, greened.*
3. **Loeffler's Blood-serum.**
   Stroke *invisible, scanty, moderate, abundant.* Form of growth, *filiform, echinulate, beaded, spreading, plumose, arborescent, rhizoid.*
   Elevation of growth, *flat, effuse, raised, convex.*
   Lustre, *glistening, dull, cretaceous.*
   Topography, *smooth, contoured, rugose, verrucose.*
   Chromogenesis (8).....
   Medium *grayed, browned, reddened, blued, greened.*
   Liquefaction begins in.....d, complete in.....d
4. **Agar Stab.**
   Growth *uniform, best at top, best at bottom; surface growth scanty, abundant; restricted, wide-spread.*
   Line of puncture, *filiform, beaded, papillate, villous, plumose, arborescent; liquefacting*
5. **Gelatin Stab.**
   Growth *uniform, best at top, best at bottom.*
   Line of puncture, *filiform, beaded, papillate, vil plumose, arborescent.*
   Liquefaction *crateriform, napiform, infundi form, saccate, stratiform;* begins in.....
   complete in.....d.
   Medium *fluorescent, browned,.....*
6. **Nutrient Broth.**
   Surface growth, *ring, pellicle, flocculent, membran none.*
   Clouding *slight, moderate, strong; transient, sistent; none; fluid turbid.*
   Odor, *absent, decided, resembling .....*
   Sediment, *compact, flocculent, granular, flaky, v on agitation, abundant, scant.*
7. **Milk.**
   Clearing without coagulation.
   Coagulation *prompt, delayed, absent.*
   Extrusion of whey begins in.....days.
   Coagulum *slowly peptonized, rapidly peptonized.*
   Peptonization begins on....d, complete on....
   Reaction, 1d...., 2d...., 4d...., 10d...., 20d.
   Consistency, *slimy, viscid, unchanged.*
   Medium *browned, reddened, blued, greened.*
   Lab ferment, *present, absent.*
8. **Litmus Milk.**
   Acid, alkaline, acid then alkaline, no change.
   Prompt reduction, no reduction, partial slow reduct
9. **Gelatin Colonies.**
   Growth *slow, rapid.*
   Form, *punctiform, round, irregular, ameboid, m lioid, filamentous, rhizoid.*
   Elevation, *flat, effuse, raised, convex, pulvir crateriform (liquefying).*
   Edge, *entire, undulate, lobate, erose, lacerate, fimbr filamentous, floccose, curled.*
   Liquefaction, *cup, saucer, spreading.*
10. **Agar Colonies.**
    Growth *slow, rapid,* (temperature.....)
    Form, *punctiform, round, irregular, ameboid, m lioid, filamentous, rhizoid.*
    Surface *smooth, rough, concentrically ringed, rad striate.*
    Elevation, *flat, effuse, raised, convex, pulvir umbonate.*
    Edge, *entire, undulate, lobate, erose, lacerate, briate, floccose, curled.*
    Internal structure, *amorphous, finely-, coars granular, grumose, filamentous, floccose, cu*
11. **Starch Jelly.**
    Growth, *scanty, copious.*
    Diastasic action, *absent, feeble, profound.*
    Medium stained.....
12. **Silicate Jelly (Fermi's Solution).**
    Growth *copious, scanty, absent.*
    Medium stained.....
13. **Cohn's Solution.**
    Growth *copious, scanty, absent.*
    Medium *fluorescent, non-fluorescent.*
14. **Uschinsky's Solution.**
    Growth *copious, scanty, absent.*
    Fluid *viscid, not viscid.*
15. **Sodium Chloride in Bouillon.**
    Per cent. inhibiting growth.....
16. **Growth in Bouillon over Chloroform,** *unrestrai feeble, absent.*
17. **Nitrogen.** Obtained from *peptone, asparagin, gl coll, urea, ammonia salts, nitrogen.*
18. **Best media for long-continued growth.....**
    .....
19. **Quick tests for differential purposes.....**
    .....
    .....

III. PHYSICAL AND BIOCHEMICAL FEATURES

1. Fermentation-tubes containing peptone-water or Sugar-free bouillon and	Dextrose	Saccharose	Lactose	Maltose	Glycerin	Mannit		
Gas production, in per cent.								
$\left(\frac{H}{CO_2}\right)$								
Growth in closed arm								
Amount of acid produced 1d.								
" " " " 2d.								
" " " " 3d.								

Group No. (1)

2. **Ammonia production,** *feeble, moderate, strong, absent, masked by acids.*
3. **Nitrates in nitrate broth,**
   Reduced, not reduced.
   Presence of nitrites.....ammonia .....
   " " nitrates.....free nitrogen.....
4. **Indol production,** *feeble, moderate, strong.*
5. **Toleration of Acids:** *Great, medium, slight.*
   Acids tested.....
6. **Toleration of Na O H:** *great, medium, slight.*
7. **Optimum reaction for growth in bouillon,** stated in terms of Fuller's scale.....
8. **Vitality on culture media:** *brief, moderate, long.*
9. **Temperature relations:**
   Thermal death-point (10 minutes exposure in nutrient broth when this is adapted to growth of organism).....C.
   Optimum temperature for growth.....C.: or best growth at 15° C, 20° C, 25° C, 30° C, 37° C, 40° C, 50° C, 60° C.
   Maximum temperature for growth.....C.
   Minimum temperature for growth.....C.
10. **Killed readily by drying:** resistant to drying.
11. **Per cent. killed by freezing** (salt and crushed ice or liquid air).....
12. **Sunlight:** Exposure on ice in thinly sown agar plates; one-half plate covered (time 15 minutes), *sensitive, not sensitive*
    Per cent. killed .....
13. **Acids produced**.....
14. **Alkalies produced**.....
15. **Alcohols**.....
16. **Ferments:** *pepsin, trypsin, diastase, invertase, pectase, cytase, tyrosinase, oxidase, peroxidase, lipase, catalase, glucase, galactase, lab, etc*.....
    .....
17. **Crystals formed:** .....
18. **Effect of germicides:**

Substance	Method used	Minutes	Temperature	Killing quantity	Amt. required to restrain growth

IV. PATHOGENICITY.

1. **Pathogenic to Animals.**
   Insects, crustaceans, fishes, reptiles, birds, mice, rats, guinea pigs, rabbits, dogs, cats, sheep, goats, cattle, horses, monkeys, man.....
2. **Pathogenic to Plants:**
   .....
   .....
   .....
3. **Toxins,** *soluble, endotoxins.*
4. **Non-toxin forming.**
5. **Immunity bactericidal.**
6. **Immunity non-bactericidal.**
7. **Loss of virulence on culture-media:** *prompt, gradual, not observed* in.....months.

BRIEF CHARACTERIZATION.

Mark + or O, and when two terms occur on a line erase the one which does not apply unless both apply.

MORPHOLOGY (2)

- Diameter over 1 μ
- Chains, filaments
- Endospores
- Capsules
- Zoogloea. Pseudozoogloea
- Motile
- Involution forms
- Gram's Stain

CULTURAL FEATURES (3)

- Broth: Cloudy, turbid; Ring; Pellicle; Sediment
- Agar: Shining; Dull; Wrinkled; Chromogenic
- Gel. Plate: Round; Proteus-like; Rhizoid; Filamentous; Curled
- Gel. Stab: Surface-growth; Needle-growth
- Potato: Moderate, absent; Abundant; Discolored; Starch destroyed
- Grows at 37° C.
- Grows in Cohn's Sol.
- Grows in Uschinsky's Sol.

BIOCHEMICAL FEATURES.

- Liquefaction: Gelatin (4); Blood-serum; Casein; Agar, mannan
- Milk: Acid curd; Rennet curd; Casein peptonized
- Indol (5)
- Hydrogen sulfid
- Ammonia (5)
- Nitrates reduced (5)
- Fluorescent
- Luminous

DISTRIBUTION

- Animal pathogen, epizoon
- Plant pathogen, epiphyte
- Soil
- Milk
- Fresh water
- Salt water
- Sewage
- Iron bacterium
- Sulfur bacterium

CHAPTER III

THE STRUCTURE AND MODE OF DEVELOPMENT OF BACTERIA—THE COMPOSITION OF BACTERIA

Bacteria are the smallest and the simplest forms of plant life known. Unlike the higher animals and plants, the entire organism consists of but a single cell. Individual cells differ in size, shape, method of cell-division, spore-formation, and the like; these features can be determined only by the use of high magnification. "Colonies" or masses of cells that develop upon certain food-substances often present definite peculiarities of form, color, consistency, and luster, which are apparent upon examination with simple lenses or with the naked eye. Similar differences may be observed among masses of larger objects: a grove of oak trees viewed from a distance too great to permit identification of the individual trees will still appear unlike a grove of pine trees. It is hence sometimes thought desirable to consider the morphology of bacteria under two heads: (*A*) the morphology of individual cells; (*B*) the morphology of masses of cells.

(A) The Morphology of Individual Cells

Dimensions.—Different kinds of bacteria vary materially in size. The average bacterium of rod shape measures about 2μ in length and 0.5μ in diameter (1μ = 1 micron or micromillimeter = $\frac{1}{1000}$ mm. = about $\frac{1}{25,000}$ inch). One large spherical bacterium that has been described measures about 2μ in diameter; the most common microbe found in suppurative processes is a spherical bacterium about 0.8μ in diameter. Considerable variation can occur within a single species. The bacillus of typhoid fever is found to range from 1μ to 3μ in length, even when the descendants of a single cell living under substantially identical conditions are examined. The largest bacteria belong, as a rule, to the group of

spirally-twisted or screw-shaped forms;* one of these† has been found to measure as much as 3.5μ in diameter. Perhaps the largest pathogenic bacterium is the spirillum or spirochete of relapsing fever, which may measure up to 40μ in length.

One of the smallest of the well-known pathogenic forms is the influenza bacillus (about 0.5μ × 0.2μ). Other micro-organisms, not surely known to be bacteria, are even smaller. The germs causing pleuropneumonia in cattle are so minute as to appear like mere points when viewed with a magnification of 2000 to 3000 diameters. The germ of foot-and-mouth disease will pass through the pores of the finest Berkefeld filter, and is so small as to be invisible under the highest lenses, but it can be cultivated by the usual laboratory procedures and its presence can be demonstrated by inoculation into susceptible animals. It is possible that other diseases, the causes of which are at present unknown, will be found to be due to ultramicroscopic organisms. It has been shown, for example, by Reed and Carroll,‡ that the virus of yellow fever, which is of unknown but probably protozoan nature, will pass through the pores of a compact porcelain filter. Special methods, such as microphotography by the ultra-violet light-rays§ and strong illumination of a dark field, the "ultramicroscope" of Siedentopf and Szigmondy,‖ have been employed in the hope of rendering visible ultramicroscopic forms of life. Up to the present, however, these methods have not been successful in revealing the existence of hitherto unknown pathogenic micro-organisms.

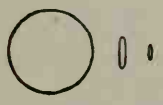


Fig. 13.—Comparative size of human red blood-corpuscle, 6.9μ; typhoid bacillus, 2.4μ × 0.5μ; and influenza bacillus. 0.5μ × 0.2μ.

The Normal Forms of Bacteria.—While varied and complicated structures are found among certain other groups of unicellular

* A bacillus (B. bütschlii), however, studied by Schaudinn (Arch. f. Protistenk., 1902, 1, p. 306) measures from 50μ to 60μ in length and from 4μ to 5μ in width.

† Spirillum colossum (Centralbl. f. Bakt., 1902, Abt. II, 9, p. 608).

‡ Reed and Carroll: Amer. Med., 1902, 3, p. 301.

§ Köhler: Ztschr. f. wiss. Mikrosc., 1904, 21, p. 129.

‖ Berl. klin. Wochensch., 1904, 41, p. 862.

organisms (diatoms, desmids, radiolaria), the forms of bacteria are very simple, and comprise only three principal types—the sphere, the rod, and the spiral. Under normal and uniform conditions of life each form breeds true, the spherical forms producing only spheres and the rods, again, only rods. It is true that immediately after cell-division a spherical bacterium may be somewhat flattened, or that immediately after the division of a short rod the daughter cells may appear almost spherical, but these temporary appearances do not affect the main distinction. Three forms, typified respectively by a ball (*coccus* or *micrococcus*), a rod (*bacillus*), and a spiral (*spirillum*), include the best-known and most thoroughly studied bacteria. In addition to these three, there is a group of closely related organisms, similar in many points to the groups already mentioned, but differing from them in being somewhat larger, and especially in exhibiting well-marked filamentous and branching characters. These higher forms of bacteria are known as *trichomycetes* (sometimes, but erroneously called *streptothrices*). Transition forms exist between these several groups; certain micro-organisms are difficult to classify exactly. The tubercle bacillus, for example, under ordinary conditions, is a typical rod, but sometimes produces branching filaments, and has been placed by some writers with the *trichomycetes*.

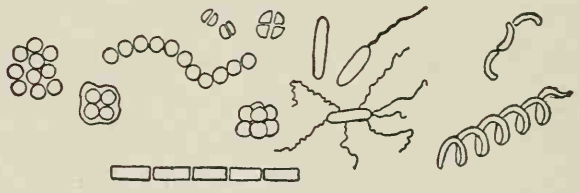


Fig. 14.—Forms of bacteria.

More bacilli are known than cocci, and more cocci than spirilla. Migula* enumerates 833 bacilli, 343 cocci, and 96 spirilla, a total of 1272; and Matzuschita† has tabulated descriptions of 1325 bacteria showing a similar proportional distribution among the several groups.

Involution and Degeneration Forms.—Under constant and favorable conditions of life each kind of bacterium generally exhibits a true constancy of form. Long-continued growth in arti-

* Migula: "System der Bakterien," Jena, 1900.

† Matzuschita: "Bakteriologische Diagnostik," Jena, 1902.

ficial culture-media, however, appears to have an injurious effect upon certain varieties of bacteria. In old cultures or in cultures kept under relatively unsuitable conditions many bacteria pass into unusual forms which are plainly the result of degeneration, and indicate that the cell has received some damage from untoward physical and chemical influences. These degenerative or involution forms often depart very widely from the typical form, and

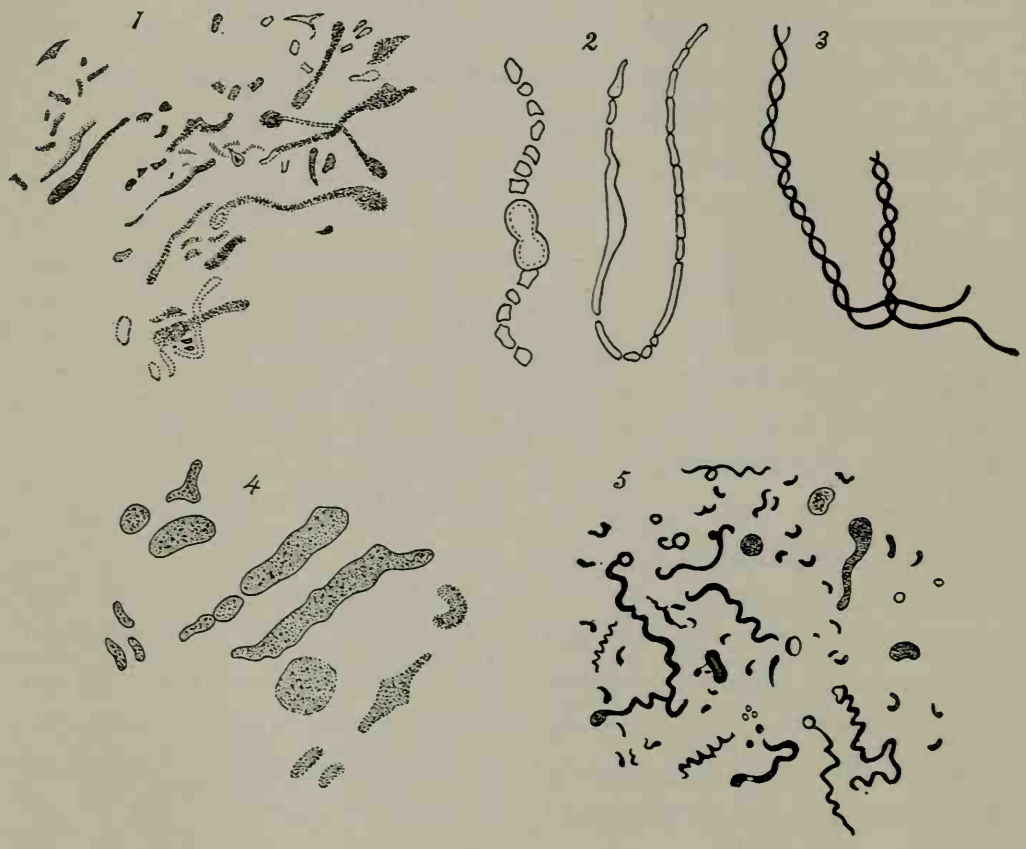


Fig. 15.—Involution forms of bacteria (enlarged about 1000): 1, Bacillus proteus mirabilis (Hauser); 2, Bac. aceticus (Hauser); 3, spirilla form of Bacillus anthracis (Petruschky); 4, involution forms of Bac. halophilus (Russell); 5, Spirillum choleræ (van Ermengem).

sometimes give to a pure culture the appearance of being contaminated by a foreign organism. Certain bacteria are especially prone to produce involution forms, and in at least one case, that of the plague bacillus, the occurrence of involution forms upon a particular culture-medium (nutrient agar, containing 2.5 to 3.5 per cent. NaCl) has been thought to be characteristic and to serve as a valuable aid to the differential diagnosis of the organism.

Monstrosities and abnormalities are sometimes observed in bacteria contained in animal tissues or fluids (plague bacillus, cholera spirillum), and although these may bear little resemblance to the typical form of the species, such involution forms are known to be alive and capable of development. The branching filaments that are occasionally observed in cultures of the tubercle bacillus, diphtheria bacillus, and other forms are believed by many to be degenerative rather than truly developmental. Loeb* has shown the influence of osmosis upon the production of branching in the typhoid and tubercle bacilli. Probably in some cases the so-called involution forms are degenerative, in others simply teratological.

The Finer Structure of Bacteria.—Corresponding to the simplicity of outer form, the internal structure of bacteria is relatively undifferentiated. Some definite structural features can, however, readily be made out. Many bacteria, perhaps all, are provided with a *capsule*, which originates from the outer layer of the cell-membrane; in stained preparations it can sometimes be seen surrounding the cell like a halo. The possession of capsular substance is believed by many investigators to be an attribute of all kinds of bacteria, although the substance is much more highly developed in some forms than in others. Certain organisms in which it is particularly conspicuous are commonly called the capsulated bacteria. Slimy cultures, such as those of B. mucosus capsulatus, page 260, characterize the capsulated forms. The capsule is generally demonstrated most easily in preparations made directly from animal tissues, as is notably the case with the micrococcus of pneumonia, but it can also be seen in specimens from ordinary cultures, if appropriate methods are used.† Capsular substance is often formed abundantly in milk cultures. Buerger‡ finds that the presence of serous fluid in culture-media favors the development of capsules and that the capsules of the pneumococcus can be readily demonstrated in preparations made from cultures on glucose-serum-agar.

The *cell-membrane* is chiefly remarkable for its chemical composition, since it differs from the cell-membrane of the higher plants

* Loeb: Jour. Med. Res., 1902, 8, p. 415.

† Boni: Centralbl. f. Bakt., 1900, 28, p. 705.

‡ Buerger: Jour. Infect. Dis., 1907, 4, p. 426.

in not containing cellulose. By many writers the membrane is regarded merely as the slightly differentiated outer portion of the cell-substance, and as deserving the name ectoplasm rather than cell-membrane. Its chemical character indicates its close relationship to the living protoplasm of the cell, as does also the fact that the flagella, or organs of locomotion, probably take their rise from this layer.

The nature of the *cell-substance* or entoplasm of bacteria has been the subject of much controversy. Especially have questions as to the character, disposition, and even the existence of nuclear material (chromatin) given occasion for many differences of opinion. The fact that the cell stains uniformly by ordinary methods has led, on the one hand, to the view that a bacterium is composed of cytoplasmic material without any nucleus, and, on the other hand, to the opposite opinion, that it is composed altogether or almost entirely of nuclear matter (chromatin), with possibly a thin outer envelop of cytoplasm. The latter view is supported by the great affinity shown by the bacterial cell-substance for the ordinary nuclear stains as well as by the capacity of the cell for very rapid cell-division. Considerable biologic significance attaches to the structure of cells so simple and presumably so primitive as bacteria, and the questions concerned have aroused widespread interest. Perhaps the most satisfactory view is that advanced by Zettnow,* which is based largely upon his own researches, especially upon some remarkable observations on large spirilla which he succeeded in staining in a living and even motile condition, thus avoiding the production of artificial changes. Zettnow regards the cell-body of bacteria as composed largely, and in the case of certain vibrios almost wholly, of chromatin mingled with varying amounts of cytoplasm, a view not unlike that first advanced by Bütschli.†

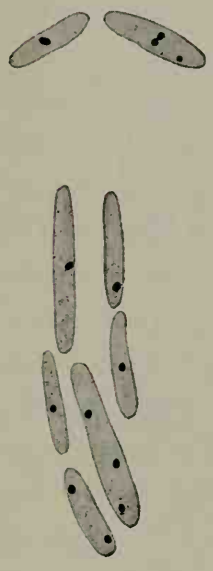


Fig. 16.—Chromatin granules in Bacillus megatherium (after Zettnow).

* Zettnow: Zeitschr. f. Hyg., 1899, 30, p. 18.

† Bütschli: "Ueber den Bau der Bakterien," Leipzig, 1890.

In most cases the chromatin, instead of being gathered together in a fairly compact mass or definite nucleus, is fragmented and distributed irregularly through the body of the cell (Fig. 16). On the whole, the researches of Zettnow, Vejdovsky, and others make it fairly certain that bacteria contain both chromatin and cytoplasm, and that the chromatin is present in great abundance, but varies in amount and in position in different cells, and occurs most frequently in a finely divided condition.

When certain kinds of bacteria are treated with methylene-blue, various granules in the cell are observed to stain differently from the substance of the cell-body, for example, red against a blue background. These are the so-called *metachromatic granules*, about the nature of which opinion is still at variance. These granules are sometimes scattered through the cell-substance, sometimes massed at either pole, where they constitute the "polar granules" observed in the plague bacillus, the glanders bacillus, and other bacteria. In certain species the metachromatic granules are particularly easy to demonstrate, and their abundance may even constitute a character of some differential value (diphtheria bacillus). It seems probable that substances of radically diverse physiologic significance have been classed as metachromatic granules. In some instances such granules are simple degeneration products; in others they doubtless bear some important relation to the physiologic activities of the cell. They have even been compared, although on insufficient grounds, to the centrosomes of more highly specialized cells. It is more likely that they are in large part reserve food-substance. A. Meyer* has shown microchemically that some of the granules are fat, some glycogen, others a lecithin-like substance, and still others a peculiar protein-like compound. It is an interesting fact that metachromatic granules are usually found in greatest abundance in the cells of the most vigorous cultures. The view advanced by a few writers, that some relation exists between the virulence of a culture and the richness of the cell in granules, has not been established.

Motility and the Organs of Locomotion.—Many kinds of bacteria are observed to be motile under the conditions in which bacteria are usually studied. Some of those forms in which motion

* Meyer, A.: Centralbl. f. Bakt., Abt. II, 1900, 6, p. 339.

has never been observed may perhaps possess the power of locomotion under certain unusual conditions. Independent bacterial motion is a true movement of translation, and is to be distinguished from the oscillating or quivering movement exhibited by all very minute particles suspended in water or other suitable fluids. The latter movement is the so-called "Brownian movement," and is a purely physical phenomenon due to surface tension, not to the activities of the living cell. Both dead bacilli and living non-motile bacilli show the Brownian movement, just as do other small particles freely suspended in a fluid. In particular cases where motility is sluggish it is often difficult to determine whether the changes in position that are observed are independent or are simply manifes-

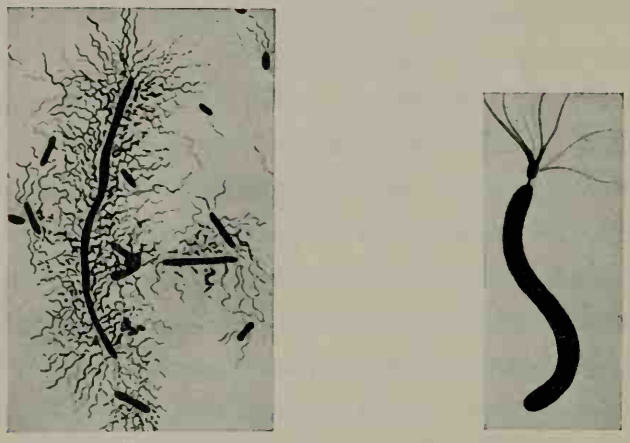


Fig. 17.—Flagella; Proteus vulgaris and large spirillum belonging to the group of sulfur bacteria (Zettnow).

tations of the Brownian movement. Many bacteria are found to be motile when they are examined after removal from certain culture-media, but are non-motile if they have been grown on other substances. One of the familiar instances of this sort is the case of the colon bacillus, which is motile when examined from young colonies on gelatin or agar, but is frequently non-motile when taken from broth. Conflicting statements concerning the motility of an organism often depend upon the fact that observations have not been made under comparable circumstances.

The rate at which a bacterium moves has been approximately measured. The typhoid bacillus may travel a distance of 4 mm., or about 2000 times its own length, in one hour; the cholera spiril-

lum may attain for short distances a speed of 18 cm. per hour.

The power of locomotion in bacteria depends upon the possession of *flagella*, long, fragile, filamentous appendages which originate from the outermost layer of the cell, or, according to some observers, from the capsule, and by virtue of their power of contractility drive the bacterium through the water. Flagella have been seen in the living, unstained cell (large spirilla) by some observers, but ordinarily special methods must be applied to reveal their presence (p. 48). Differences exist in respect to the position of the flagella on the cell-body: some forms possess only a single flagellum at one pole (*monotricha*, cholera spirillum); others possess a flagellum at each pole (*amphitricha*, many spirilla); others possess a tuft of flagella at one pole (*lophotricha*, certain large spirilla); and others have flagella projecting from the whole body of the cell, from the sides as well as the poles (*peritricha*, typhoid bacillus and many other bacilli). In some non-motile bacteria no flagella have ever been observed (*atricha*, anthrax bacillus). The number of flagella on the body of peritrichous bacteria varies considerably. Even closely allied bacterial species may differ in respect to the number of flagella they possess. The typhoid bacillus, for instance, possesses, as a rule, more flagella (ten to twelve) than the closely related colon bacillus (two to six). The majority of actively motile bacteria belong either to the bacilli or the spirilla; very few micrococci are motile under ordinary conditions,* and no motile trichomycetes have been described.

Growth and Cell-division.—A bacterium can increase in size up to a certain point; the maximum size attainable, as among the higher forms of life, is singularly constant for each species. When the maximum is reached, cell-division occurs by simple partition or fission, dividing the cell into approximately equal halves. Possibly division of the nuclear substance precedes that of the cell-body (Nakanishi†). Among bacilli and spirilla cell-division always takes place at right angles to the long axis of the cell; among the cocci division may occur only in one plane, resulting in the formation

* According to the investigations of Ellis (Centralbl. f. Bakt., Abt. II, 9, 1902, p. 546), all forms of micrococci possess flagella and are motile under favorable conditions. This assertion has not been confirmed.

† Nakanishi: Centralbl. f. Bakt., 1901, 30, pp. 97, 145, 193, 225.

of chains (*streptococci*); or in two planes, giving rise to flat sheets of cells or irregular masses (*staphylococci*); or in three planes, producing cubical bales or packets (*sarcinæ*).* After cell-division the cells may remain connected (*streptobacilli* or *streptococci*) or they may become speedily disunited. Bacilli and spirilla show some elongation before division; cocci, as a rule, do not, although some cocci exhibit an increase in the diameter of the cell without any alteration of its spherical form.

Under favorable conditions cell-division may take place quite rapidly (hay-bacillus, thirty minutes; cholera vibrio, twenty minutes). Such rapidity of cell-division is sometimes referred to as if it were a peculiar quality of bacteria, but as a matter of fact the embryonic cells of many higher forms of life divide quite as rapidly as bacteria.

The remarkable thing about bacterial cell-division is not so much the rapidity with which one cell-division succeeds another, as the fact that a very short time suffices for the growth of the young cell to maturity. A young bacterial cell attains full size and acquires the capacity to produce in its turn an independent organism much sooner than most other forms of life. This rapid reproduction of distinct individuals is plainly different from the multiplication of embryonic cells among higher organisms. The rate of multiplication among the more complicated protozoa, which are also one-celled organisms, is considerably less rapid. Calkins† has shown that Paramœcium divides about once or twice in twenty-four hours. It has been estimated that if bacterial multiplication went on unchecked, and the division of each cell took place as often as once an hour, the descendants of each individual would in two days number 281,500,000,000, and that in three days the progeny of a single cell would balance 148,356 hundredweight! No living organism, however, as was pointed out long ago by Darwin, can increase in exact geometric progression, for various checks and hindrances are always placed upon its multiplication by natural

* It may be noted that when the cells become separated after division and change their position it is difficult, if not impossible, to trace the direction of the division plane. Some of the organisms classed as staphylococci are said to be able to divide in three planes. (Fischer: "Structure and Function of Bacteria," tr. Oxford, 1900, p. 19.)

† Calkins: Archiv f. Entwickelungsmech., 1902, 15, p. 139.

causes. In the case of bacteria a potent influence that tends to prevent unlimited multiplication is found in the interference with growth caused by the substances produced by bacteria themselves. Acids and other injurious products are commonly formed by bacteria during the disintegration of their food-substances, and accumulate in the immediate surroundings of the organisms, where they often inhibit all further multiplication. This is undoubtedly one of the ways in which bacterial growth is checked, although other factors, such as insufficient food, lack of moisture, unsuitable temperature, and the competition of other kinds of bacteria, also play a part.

Spore-formation.—The true *spores* or *endospores* of bacteria resist a heat of from 70° to 100° C., and are characterized by definite structural and physiologic qualities. In shape they are approximately spherical or oval. Spores are gifted, as a rule, with a very much higher resistance to all sorts of injurious influences than are the vegetative cells from which they spring. In addition to their great resistance to high temperatures, to the action of poisons and the like, they stain with great difficulty, these characteristics being probably due to their extraordinarily dense and compact structure. The highly refractive character of the unstained spore is also connected with the concentrated character of the spore substance.

An assembling or concentration of the nuclear material seems to precede spore-formation in some cases and constitutes the spore primordium. As a rule, a single cell forms only one spore; exceptions to this are very rare. Spore-formation among bacteria, therefore, is not a reproductive device for multiplying the number of individuals of the species, but more probably signifies the assumption of a resistant stage for the purpose of meeting the advent of unfavorable conditions of life.

The spore may be formed in any part of the cell, its position being generally constant in the same species. In some cases it does not exceed the diameter of the parent cell (anthrax bacillus); in others it may cause a bulging out of the wall of the cell at the point where it lies (Fig. 18). If a swollen spore is formed at one pole, a "drumstick" appearance (tetanus bacillus) may result, or if it lies centrally the cell will become "spindle-shaped," a form to which the name clostridium has been given.

The spore of the anthrax bacillus, when brought under favorable conditions, shows first a change in the refractive property of the spore-substance; this is followed by a slight elongation of the spore, with a final bursting through of the spore-membrane and the outgrowth of a short rod, which then divides in the usual manner. The new outgrowth of the anthrax bacillus takes place at the pole of the spore; in the closely related hay bacillus it is at the equator. Other forms of bacteria exhibit intermediate methods of germination, and irregularities sometimes occur in the development of spores of the same species.

Spore-formation is not very common among bacteria. It is most frequently observed in b a c i l l i, less commonly in spirilla, and very r a r e l y in micrococci. A noteworthy correlation of characters is shown in the almost unfailing occurrence of spore-formation in strict anaërobes (p. 73). Spore-forming aërobic bacteria are relatively less abundant. Saving certain anaërobic bacilli (bacillus of tetanus, of malignant edema, and a few others), only one spore-forming bacterium, the anthrax bacillus, is known to be pathogenic for man, a fortunate circumstance that materially facilitates and simplifies the disinfection and treatment of infectious diseases.

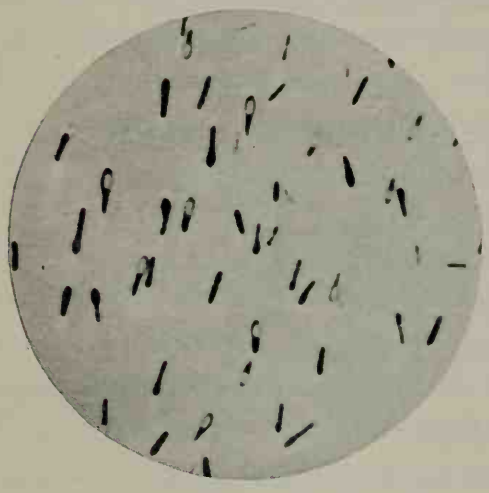


Fig. 18.—Spores, bacillus of symptomatic anthrax. Methylene - blue stain (Kolle and Wassermann).

The conditions under which bacteria form spores vary with the nature of the organism. The bacillus of anthrax, as a rule, forms spores only when in contact with free oxygen, a fact that has a direct practical bearing upon the mode of disposal of the carcasses of cattle dying from this disease. The tetanus bacillus, on the other hand, and the anaërobes in general, form spores in the entire absence of oxygen. A suitable temperature is essential to the formation of spores: the anthrax bacillus forms spores most abundantly at about 30° to 32° C., and will not produce spores below a temperature of about 12°, its optimum of vegetative multiplication being

about 37°. Lack of food is apparently not an adequate stimulus to spore-formation. In all cases a period of uninterrupted vegetative multiplication precedes the appearance of spores, and the conditions necessary for the production of spores seem to arrive simultaneously for most of the cells in a culture. In at least some cases the cause of spore-formation is to be found in an accumulation of metabolic products in the culture; these may perhaps be acids, perhaps other injurious compounds.* It must not be forgotten that although some bacteria do not form spores under the conditions in which they are observed, it does not follow that they may not form spores under other and more suitable conditions. It is not possible to imitate with precision the "natural" conditions of life for all micro-organisms, and there is no complete justification for the assumption that because an organism has never been observed to form spores it never does so.

Physiologically the spore is to be considered as a resting-stage. It serves to tide the species over a period of dryness, famine, or unsuitable temperature, and to preserve alive in a hostile environment a sufficient number of individuals until such time as favorable conditions recur. The spore stage is, in fact, physiologically analogous to the periods of hibernation or estivation among higher forms of life. In this resting state the living matter of the spore may remain dormant for years or even for decades.

(B) The Morphology of Masses of Cells

In the case of many species of bacteria a single cell, when planted in a favorable medium and allowed to develop under suitable conditions of moisture, temperature, and air-supply, will in a few hours or days develop a "colony" so large that it can be plainly seen by the naked eye. In some instances such masses of cells, especially when the growth occurs upon certain culture-media, possess salient peculiarities which are highly characteristic of the species. In others the differences between colonies of closely allied species are exceedingly subtle, and can be detected at times only by a trained eye. Growths upon the nutrient gelatin commonly used as a culture-medium are especially characteristic; on this

* Migula: "System der Bakterien," Jena, 1897, I, p. 177.

medium the morphologic appearance of a mass of typhoid bacilli, for example, is quite distinct from that of a mass of anthrax or of diphtheria bacilli. The differences between the gelatin colonies of closely related organisms are often, however, as in the case of some members of the colon-typhoid group, almost or quite inappreciable.

The character of the colonies is profoundly affected by the density and viscosity of the culture-medium (Whipple*) and by the physical conditions under which the colonies develop (Dunham†); and much less weight can be attached to small differences between colonies than has been sometimes supposed. Upon nutrient agar the morphology of bacterial colonies is less distinctive than upon gelatin; the colonies upon potato and other solid food-substances are, as a rule, still less characteristic.

Besides the shape, size, and general structure of bacterial colonies, color is sometimes of service in differential diagnosis. Certain species produce variously colored pigments which are more or less characteristic of the organism forming them. A common microbe of suppuration owes its name of the "golden pus coccus" to its production of a golden-yellow pigment. The bacillus of green pus is also conspicuous for its pigment. It must be remembered, however, that among bacterial colonies, as among living organisms generally, there is no quality so variable as color, and that, as a rule, implicit dependence cannot be placed upon the pigmentation of a bacterial colony even as a mark of varietal or racial difference.

Considering all the facts, it must be admitted that great stress should not be laid upon the morphology of masses of bacteria as an aid in distinguishing different kinds. The mass-morphology, like the individual morphology, is subject to wide variation under varying conditions of life, and can be regarded as only one item in the sum-total of characters that go to make up the concept of a bacterial species. As has been pointed out by Marshall Ward,‡ "the attempt to determine species of bacteria by ordinary macroscopic methods leads to difficulties of the same kind as would be

* Whipple: Technology Quarterly, 1902, 15, p. 127.

† Dunham: Science, 1903, 17, p. 372.

‡ Ward, Marshall: Proc. Roy. Soc., 1897, 61, p. 415.

met if we tried to differentiate species from the marks presented by masses of trees in forests from a distance—say, in a balloon. A forest of a given species of tree would appear very different at different seasons, and according to its age, the kind of soil, climate, and so on, and the treatment it had received previous to planting."

The Chemical Composition of Bacteria.—The bodies of bacteria contain from about 80 to 88 per cent. of water, the amount showing considerable variation and depending partly on the nature of the organism, partly on the culture-medium. The ash is largely phosphoric acid, the P_2O_5 content often reaching as high as half the total ash weight (tubercle bacillus, 55.23 per cent., de Schweinitz and Dorset*). Sulfur, potassium, chlorin, and calcium are also present in notable amounts, together with usually smaller quantities of magnesium, iron, silica, etc. Some forms of filamentous bacteria, found especially in sewage-polluted water, contain in their protoplasm granules of sulfur (Beggiatoa). Others have notable deposits of iron in the sheath that surrounds the rather large filaments (Crenothrix).

Among the bacteria, cellulose, as in the lower fungi generally, is conspicuous by its absence; but another and somewhat similar carbohydrate, designated as hemicellulose, is often present in abundance. Starch-like substances, staining blue with iodin, are also observed. It is a peculiarly interesting fact that a substance closely related to *chitin*, if not identical with it, has been found in a number of bacteria. It has been noted that in many respects the bacteria resemble the lower animals in their chemical composition.

Characteristic nitrogenous compounds, namely, nuclein, hypoxanthin, guanin, and the nuclein bases, such as adenin, occur practically constantly in bacteria. Regarding the nature of the true protein substances in bacteria little is known. Much attention has been paid to the toxic constituents of the bacterial cell, and these substances are referred to in another place. The diffusible products of bacteria are also considered elsewhere (p. 90).

* Centralbl. f. Bakt., 1897, 22, p. 209.

CHAPTER IV

THE EFFECT OF PHYSICAL AND CHEMICAL AGENTS UPON BACTERIA

It is a well-known biologic fact that various physical and chemical agencies affect profoundly the vital phenomena of all living cells; physical and chemical factors determine inexorably whether a micro-organism shall thrive and multiply, whether it shall lead a merely dormant existence or shall altogether perish. Among the most important of the natural environmental influences are temperature, light, moisture, oxygen-supply, and food-supply.

Temperature Relations.—Many bacteria show great adaptability to temperature conditions. The hay bacillus (B. subtilis) is able to multiply at 6° C. and also at 50° C. Three temperature limits may be distinguished: a minimum, or the lowest point at which growth occurs; an optimum, or the temperature of most luxuriant growth; and a maximum, or the highest temperature at which growth can take place. The position of these three points differs greatly for different species. The minimum for some bacteria may lie above the maximum for others: B. thermophilus, a species found in soil and fermenting manure, will not grow under certain conditions below 42°; * B. tuberculosis will not grow above 42°, while B. phosphorescens will not grow above 37°. The optimum for B. phosphorescens is 20°, for the hay bacillus 30°, for B. tuberculosis 38°, and for B. thermophilus 63° to 70°. Some bac-

* It has been shown by Rabinowitsch (Zeit. f. Hyg., 1895, 20, p. 154) that while many of the thermophilic bacteria are able to grow only at temperatures above 50° when in contact with air, they are able under anaërobic conditions to grow at the ordinary incubator temperature (37.5°), or even as low as 34°. Such species appear adapted both to an anaërobic life in the animal body at about 37° and also to aërobic life at the high temperatures found in fermenting manure.

teria are able to multiply at or very near the freezing-point,* while others are said to be able to multiply at 75° to 77°. Setchell† has found bacteria living in the water of hot springs at a temperature of 89° C.! The range of temperature within which growth can take place also varies greatly in different species. Bacteria that have become habituated to living in the mammalian body (*e. g.*, B. tuberculosis) have a much narrower range than those whose habitat is the outer world (B. subtilis). The optimum temperature for most of the bacteria pathogenic for man lies, as might be expected, in the neighborhood of the normal temperature of the human body (37° C.). The following table gives the approximate temperature relations for several species:

Bacterium.	Minimum.	Optimum.	Maximum.
B. phosphorescens	0.0	20.0	37.0
B. fluorescens, var. liquefaciens	5.0	24.0	38.0
B. subtilis	6.0	30.0	50.0
S. choleræ	8.0	37.0	40.0
B. anthracis	14.0	37.0	45.0
B. tuberculosis	29.0	38.0	42.0
B. fitzianus	....	40.0	45.0
B. thermophilus	42.0	63–70	72.0

The wide range here shown in respect to the maximum and minimum temperatures that permit growth is paralleled by the diversity in bacterial resistance to extreme temperatures. Spores are always much more resistant to heat than vegetative forms, and some species when in the spore-stage can withstand the temperature of boiling water for upward of sixteen hours. The vegetative forms of most bacteria, on the other hand, are killed at 55° to 58° C. by ten minutes' exposure in the presence of moisture. As is well known, dry heat is much less effective as a germicide than steam: in a dry atmosphere temperatures ranging from 140° to 180° C. must be employed to insure sterilization. If steam under pressure be used, as in the autoclave, exposure for fifteen minutes to a temperature of 125° C. is sufficient to destroy all known microbes.

* Forster: Centralbl. f. Bakt., 1887, 2, p. 337; M. Müller: Arch. f. Hyg., 1903, 47, p. 127.

† Setchell: Science, 1903, 17, p. 934.

The difference between moist and dry heat doubtless depends upon the fact that the chemical or physical changes that cause the coagulation of protein or death of protoplasm take place, like such actions generally, more readily in the presence of water.

The thermal death-point has been determined with considerable precision for the common micro-organisms. The usual method consists in exposing, for ten minutes, a suspension of the organisms in broth or salt solution to the action of a given temperature. That temperature at which all the organisms are destroyed is said to be the thermal death-point for the species. These fatal temperatures are lower than is popularly supposed. The thermal death-point (ten minutes' exposure) for the cholera spirillum is 58° to 60° C.; for the anthrax bacillus, vegetative form, 60° C., spore, 100° C.; for the typhoid bacillus, 58° to 60° C., and for the tubercle bacillus, 65° to 70° C. Under certain circumstances the thermal death-point may be raised. It has been shown that while tubercle bacilli in suspension in milk are destroyed at 60° in fifteen to twenty minutes, the pellicle that forms on the surface of milk during exposure at 60° may contain living bacilli after sixty minutes.* It may be noted that the thermal death-point of those bacteria that are at all likely to be present in polluted water is low (57° to 60° C.), and since these micro-organisms do not form spores, the practice of simply bringing water to the boiling-point suffices to insure its safety for drinking purposes.

Bacteria are much less sensitive to low than to high temperatures. The common microbes of water and soil, and also typical pathogenic bacteria like the typhoid and diphtheria bacilli, have been exposed for some days to the temperature of liquid air (about —190° C.) without destroying their vitality or sensibly impairing their biologic qualities. Cultures of bacteria have even been exposed to the temperature of liquid hydrogen (about —250° C.)† with the same negative result. On the other hand, when bacteria are frozen in water during the formation of natural ice, the death-rate is high. The questions relating to the duration of life of bacteria in natural

* Th. Smith: Jour. Exp. Med., 1899, 4, p. 217.

† This temperature is far below that at which any chemical reaction is known to take place, and is only about 23 degrees above the absolute zero point, a temperature at which, it is believed, molecular movement ceases.

ice possess an important practical interest, and will be discussed elsewhere (p. 283).

Light.—That light affects the metabolism of the living cell is well known, and the various reactions to light that are exhibited by the higher organisms have been the subject of much investigation.

In connection with the study of bacteria the germicidal influence of light has received most attention. Diffuse daylight has been found to exercise a hindering effect upon bacterial growth and metabolic activity. Direct sunlight is highly injurious to certain forms of bacterial life, many micro-organisms being killed almost instantly when exposed to the full action of the sun's rays. That the unfavorable influence of sunlight is not due to the heat-rays is shown by the use of a screen (alum solution) which intercepts the heat rays, but allows the germicidal rays to pass through.

Since light has no effect upon bacteria in a vacuum, it may be inferred that the changes brought about by light under ordinary conditions are primarily oxidation processes of a kind incompatible with the continued life of the cell.

The action of light on bacteria has been picturesquely shown by protecting certain portions of a plate seeded with bacteria, and allowing the rest of the plate to receive the full effect of the sun's rays. In properly handled plates colonies of bacteria will develop in the shaded portions, but no colonies will appear in the exposed portions (Fig. 19).

The blue and violet rays have the most marked germicidal power, and bacterio-photographs of the solar spectrum have been obtained (Fig. 20).

Unexplained and insufficiently understood differences have been observed in the action of light upon different species of bacteria. It is worthy of remark that spores, perhaps because of oily substances that they contain, are especially sensitive to light.

The electric light exerts a germicidal influence similar to that of the sun's rays. The Röntgen rays have not yet been definitely shown to exert any germicidal effect.

Moisture.—Many of the higher forms of life display considerable resistance to drying. The small aquatic worms known as rotifers will revive after months or even years of prolonged desiccation. If, however, the actual body substance is not, like the rotifer,

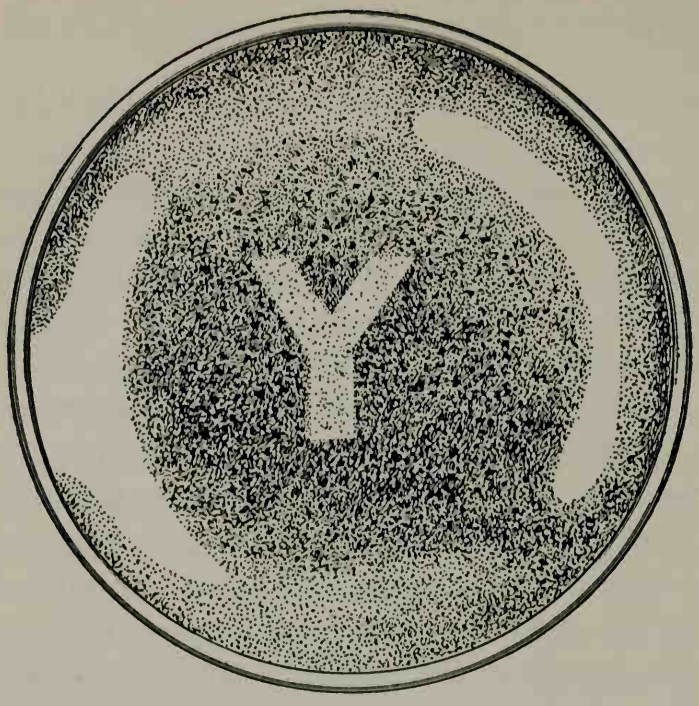


Fig. 19.—An agar plate of anthrax spores exposed behind a stencil plate Y from 12.15 to 3.15 p. m. on March 27, and then incubated at 20°–22° C., and photographed at intervals. The photograph was taken as a transparency, against a N-window. The two crescentic areas are due to the agar-film not completely covering the plate in this case. Seventy-two hours' incubation (H. Marshall Ward).

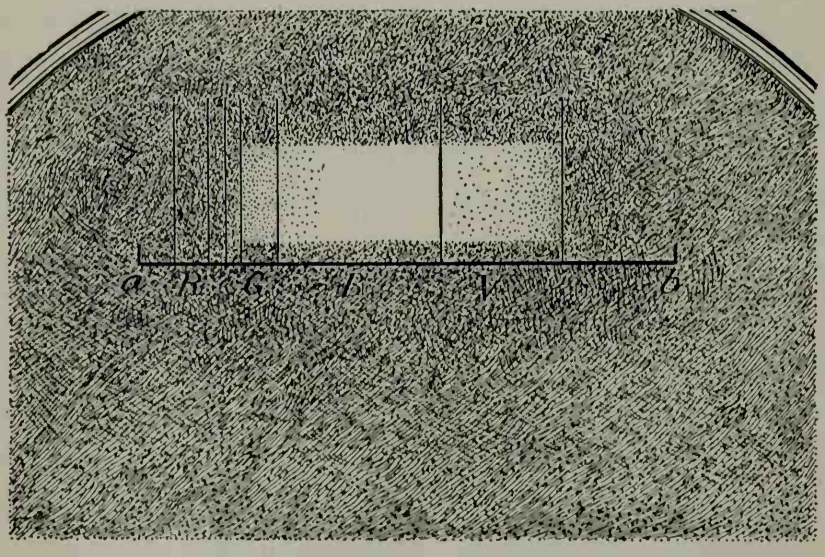


Fig. 20.—Bacterio-photograph of the spectrum (H. Marshall Ward). Agar plate of spores of Bacillus anthracis, exposed to the action of the solar spectrum for five hours on August 16th (11 a. m. to 4 p. m.). The spectrum was very bright, and nearly, though not quite, pure. The photograph shows the condition of the plate after twenty-four hours' incubation at 25° C. This figure shows the limits of the various regions of the visible spectrum marked on it (*R*, red; *G*, green; *B*, blue; *V*, violet). The base line *a*—*b* shows the length of the slot through which the spectrum shone on the plate. All parts of the agar plate not exposed are rendered evenly opaque by the colonies germinated out from the spores; similarly the spores in the infra-red, red, orange-yellow are unhurt, as are those to the other end of the violet. The action of the light begins in the green-blue and attains its maximum in the blue-violet, near the Fraunhofer's line *G*.

protected by a gelatinous capsule, the complete removal of moisture speedily destroys life. Even the seeds of the higher plants which are specially adapted for resistance to drying rarely outlast ten to twenty years.

Most of the vegetative forms of bacteria are rather quickly killed by ordinary air drying, although there are great differences among the different forms. The tubercle bacillus is one of the more resistant, the cholera spirillum one of the more sensitive, to drying. Exposure to desiccation for a few hours, or at most a few days, destroys the majority of known pathogenic microbes, so that infection through the air, except where floating bacteria are protected by their position within epithelial scales or in droplets of moisture, is not so common as popularly supposed.

The spores of bacteria are much more resistant to drying than the vegetative forms. The spores of the anthrax bacillus will germinate after remaining in a dry condition for at least ten years.

Oxygen Supply.—Bacteria may be divided into three classes with reference to their need for oxygen: the *obligatory aërobes,* or those that require free oxygen for the maintenance of their life activities; the *obligatory anaërobes,* or those that do not grow except in the almost complete absence of free oxygen; and the *facultative anaërobes,* or those that can thrive in either the presence or the absence of oxygen.

The *obligatory aërobes* comprise many of the ordinary air and water bacteria, especially those of the pigment-forming varieties. Among pathogenic bacteria the diphtheria bacillus and the cholera spirillum are forms that require a supply of free oxygen. The different kinds of aërobic bacteria vary in respect to their optimal oxygen tension. This is beautifully illustrated by the "respiration figures" pictured by Beijerinck,* which show that different kinds of bacteria grow best at different levels in fluid media, the thickest swarm of each species being at that level at which the oxygen tension is most suitable.

The discovery of an *obligatory anaërobe* by Pasteur in 1861 was the cause of one of the most important changes wrought by bacteriology in the biologic conceptions then current. All of the organisms known up to that time required free oxygen to support life, and

* Beijerinck: Centralbl. f. Bakt., Abt. I, 1893, 14, p. 837.

Pasteur's discovery was at first received with considerable incredulity. It has since been shown, however, by experiments of great precision, that bacteria actually exist which are able to live and multiply in the almost complete absence of free oxygen, provided their food contains oxygen in suitable combinations. Anaërobes will grow in media where reduced hemoglobin remains unchanged and reduced methylene-blue shows no trace of reoxidation. The practical absence of oxygen is further demonstrated by the fact that strictly aërobic bacteria are not able to grow at all under these conditions. It has been found, however, that conditions for the growth even of the obligatory anaërobes are not afforded by the entire absence of oxygen, but by the presence of very minute quantities of oxygen, which, according to Chudiakow,* are utilized by the anaërobes in their metabolic activities. Certain anaërobes, furthermore, can become acclimated to growth in gradually rising amounts of oxygen until the original oxygen limit is greatly exceeded.

It is found experimentally that anaërobic bacteria as a class thrive best in the presence of substances capable of undergoing reduction or fermentation.† The peculiar phenomenon of anaërobiosis may perhaps be explained by supposing that anaërobes are bacteria specially qualified to obtain their needed energy from the simple splitting up of organic compounds without oxidation. Although it is true that, in its original form, Pasteur's conception of fermentation as "life without air" is no longer tenable, it cannot be questioned that in many cases anaërobic life is conditioned by the ability of an organism to ferment certain organic compounds. In a modified sense, Pasteur's explanation of fermentation as due to the adjustment of certain micro-organisms to an anaërobic mode of life affords a satisfactory view of the biologic significance of anaërobiosis. In other words, if a microbe is able to obtain the energy necessary for its life activities by reducing processes without resorting to processes of oxidation it can live an anaërobic life; if it is so addicted to an anaërobic mode of life that the presence of

* Chudiakow: Centralbl. f. Bakt., 1898, Abt. II, 4, p. 389.

† It is a common observation that many bacteria will not grow up into the closed arm of the fermentation tube except when the culture-medium contains certain sugars or other fermentable substances. The presence of certain aërobic bacteria or their products, or the products of anaërobic bacteria, also permits growth in the closed arm.

oxygen, except in minimal quantities, interferes with its habitual methods of attacking food-substances, it is an obligatory anaërobe; if, on the other hand, it can obtain energy only through the direct oxidation of organic substances, it is an obligatory aërobe.

Food-supply.—Bacteria are able to satisfy their food requirements upon the most diverse substances. Organic compounds in great variety can serve as food. Complex nitrogenous bodies, especially, which contain a large amount of available potential energy, are attacked eagerly by many species, as witnessed in the familiar phenomena of decay and decomposition. Less complex molecules can also serve as a source of energy. Many bacteria, including pathogenic forms, such as the cholera spirillum and others, will grow upon non-protein media which consist of a solution in distilled water of simple mineral phosphates and sulfates together with asparagin or ammonium salts of the organic acids (succinic, lactic, citric). Particular interest attaches to the ability of certain micro-organisms to construct their living substance wholly out of inorganic compounds. It has long been known that organisms containing chlorophyl or allied pigments were able, with the aid of the sunlight, to effect such a synthesis, but it was supposed that a sharp distinction must be drawn between the chlorophyl-bearing and the non-chlorophylaceous organisms. The ability of the so-called nitrifying organisms (Winogradsky) to develop in the presence of very simple mineral salts, and in the entire absence of organic matter of any kind, has completely overthrown this distinction (Ch. XXXI). By these organisms the energy necessary for development is obtained from the oxidation of very slightly energized compounds like the mineral ammonium salts and even nitrites. Since organic carbon compounds are also formed by the nitrifying bacteria, it follows that *a complete synthesis of organic matter is effected by these organisms independently of the presence of pigment and the action of the sun's rays.* The nitrifying organisms, some of which are able to oxidize ammonia to nitrites, and others to oxidize nitrites to nitrates, are so wedded to their particular modes of metabolic activity that they are quite unable to thrive in the presence of organic substances, a condition analogous to that presented by the obligatory anaërobes. Beijerinck and Van Delden* have reported the discovery of a remarkable

* Beijerinck and Van Delden: Centralbl. f. Bakt., Abt. II, 1903, 10, p. 33.

organism, B. oligocarbophilus, which is capable of growing in water containing merely nitrates and other fully mineralized salts, and is able to utilize in its development a volatile carbon compound of unknown nature which is present as an impurity in ordinary atmospheric air. In association with certain other bacteria it can oxidize hydrogen, perhaps according to the equation:

$$CO_2 + H_2O + H_2 = CO + 2H_2O.$$

Pure cultures of B. oligocarbophilus are capable of oxidizing and assimilating carbon monoxid!

According to Kaserer,* B. pantotrophus, by a somewhat similar process, generates formaldehyd, which it can then use as a nutritive substance.

$$CO_2 + H_2O + 2H_2 = HCHO + 2H_2O.$$

This organism is able to endure the presence of formaldehyd in a strength of 1 : 15,000.

Bacteria are frequently distinguished as *saprophytes* and *parasites*, on the basis of their source of food-supply. Saprophytes are those forms able to obtain the requisite energy for growth from dead or lifeless matter; parasites are able to thrive within or upon the living substance of various animal or plant hosts. Many parasitic organisms are able to lead also a saprophytic existence, as shown by the ability of the tubercle bacillus, the plague bacillus, and many others, to grow not only in the human body, but also upon the ordinary culture-media employed in bacteriologic laboratories. A few parasitic forms, however, are so highly specialized for a life in contact with living tissues, and even the tissues of a particular host, that they are unable to grow under any other circumstances. This appears, for instance, to be the case with the bacillus of leprosy, which is able to grow in the body of man and in apes, but resists attempts to cultivate it on lifeless food-substances or in the bodies of other animals. On the other hand, most of the ordinary water and soil bacteria are powerless to grow when introduced into the animal body, and seem entirely unadapted to a parasitic mode of life.

* Kaserer: Centralbl. f. Bakt., Abt. II, 1906, 16, p. 681.

The *concentration* and *reaction* of a nutrient substance are factors of some importance. In general, organic substances in solution are available as sources of food-supply for bacteria only when in certain degrees of dilution. A familiar instance is the speedy souring of a dilute sugar solution as contrasted with the keeping qualities of a thick syrup. The osmotic adjustment required of a bacterial cell suddenly introduced into a concentrated fluid is too great to be readily compassed.

Most pathogenic bacteria thrive best in a food-medium that reacts neutral or slightly acid to phenolphthalein. There are, however, considerable differences between the different kinds of bacteria. The cholera spirillum is quite sensitive to the presence of a very small amount of acid, while the typhoid bacillus is not checked by a distinct acid reaction. Many bacteria found in water grow best in a medium that is 1.0 per cent. to 1.5 per cent. acid to phenolphthalein.*

Other Environmental Influences.—Among other factors which have been studied with reference to their effect upon bacteria are atmospheric pressure, mechanical agitation, and electricity.

Pressures of 600 to 700 atmospheres are said by some observers to have an inhibitory effect upon putrefactive processes, but, on the other hand, others state that living micro-organisms are not affected by exposure for twenty-four hours to a pressure of 600 atmospheres. According to Roger,† a pressure of 2000 atmospheres lessens the virulence of the anthrax bacillus. The effect of pressure cannot be said to have yet been fully determined.

The evidence in respect to the influence of *mechanical agitation* upon the life of bacteria is somewhat conflicting, but, on the whole, indicates that prolonged shaking, whether moderate or violent, of a fluid containing bacteria has little, if any, influence. Shaking will, however, sometimes cause the separation of loosely cohering cells, and this may lead to a simulation of cell multiplication, if dependence be placed on a count of bacterial colonies. When glass pearls or similar objects are shaken up together with bacteria, the organisms are mechanically injured by the successive shocks and destroyed.

* The litmus neutral point is about 2.5 per cent. acid to phenolphthalein.

† Roger: Arch. de Physiol., 1895, p. 12.

Experiments made to determine the effect of the *electric current* upon bacteria have been in too many cases conducted loosely, and inferences have been drawn that have not been warranted by the conditions of the experiment. In some instances when a small amount of fluid is used, a rise in temperature is produced which is sufficient to account for the death of bacteria; in other cases death is due to the action of strongly germicidal substances, like chlorin and ozone, which are liberated by the passage of the electric current. When the effects due to heat and to the electrolytic production of gemicides are eliminated, it is very doubtful whether any direct germicidal action can be properly attributed to the electric current. Abbott* has found that with a weak current cultures of certain bacteria gather at the kathode, but if the bacteria are grown in acid-modified media they gather at the anode.

Adaptability of Bacteria to Varying Conditions of Life.— It has already been pointed out that different kinds of bacteria vary greatly in their response to different physical and chemical agencies. It is also a noteworthy fact that one and the same kind of micro-organism is able to adapt itself to widely different conditions of life. Thus, Dieudonné† has shown that by cultivating the anthrax bacillus at gradually decreasing temperatures a degree of acclimatization to cold is finally attained by this organism which enables it to grow at a temperature as low as 10° C. The adaptability to changed conditions shown by the tubercle bacillus, which when first isolated from the mammalian body grows reluctantly on artificial media, but with continued cultivation becomes more saprophytic, is another case of the same order. Still more remarkable is the acquisition by the mammalian tubercle bacillus of the power when incorporated in the body of a cold-blooded animal to grow at a very low temperature. It is probable that these adjustments to different conditions of life are in part due to the selective influences that are always at work when cultures of organisms, containing many individual cells, are exposed to a changed environment. That is to say, on raising the temperature of a culture certain cells, the least resistant, will be destroyed first, while the more resistant will survive and their descendants will inherit the resistant quali-

* Abbott: Science, June 12, 1908, p. 910.

† Dieudonné: Arb. a. d. kaiserl. Ges., 1894, 9, p. 492.

ties of the parents; eventually the whole culture by this process of continued selection will come to possess a heightened tolerance of high temperatures. In addition to this factor, however, individual adaptation on the part of the protoplasm of the individual cell may occur also, as indicated by analogous experiments with other organisms, for example, by Dallinger's results with flagellates,* which he succeeded, in the course of several years, proceeding by slow stages, in rearing up to a temperature of 70° C., when the experiment was ended by accident. At the beginning of the experiment the flagellates were killed at 23° C. Probably bacterial protoplasm likewise can become directly adjusted to changed conditions.

Effect of Chemical Substances upon Bacteria.—The phenomena of positive and negative chemotaxis are fully exemplified in bacterial life. It has been frequently demonstrated that bacteria, like other free-moving organisms, are apparently attracted by certain chemical substances in solution (positive chemotaxis) and repelled by others (negative chemotaxis). These movements are ordinarily regarded as the direct result of a chemical stimulus. According to the view held by Jennings,† the swarming of bacteria around algæ that are evolving oxygen, or around any other points where favorable nutrient conditions exist, is not to be looked upon as due to a definite attraction exerted upon the bacterial cell, but as caused simply by the tendency to remain at those points where the conditions are favorable. In the course of their aimless wanderings bacteria eventually arrive at those spots where conditions —as the oxygen tension—are highly suitable; there they remain.

The tendency of aërobic bacteria to collect near that portion of an algal filament where oxygen is being most abundantly evolved has been utilized by Engelmann in a beautiful experiment for showing the effect exerted upon assimilation by the different parts of the solar spectrum. The greatest aggregation of bacteria occurs at the red end of the spectrum (Fig. 21). indicating that the maximum assimilative activity of the algal protoplasm is proceeding at this point.

* Dallinger: Jour. Roy. Mic. Soc., 1887, i, p. 185.

† Jennings, H. S.: "Behavior of the Lower Organisms," New York, 1906, p. 39.

Many bacteria in the course of their growth give rise to substances, such as acids, which are more or less injurious to cell life. The cessation of growth which takes place after a time in cultures of bacteria upon artificial culture-media is thought by some to be due not to the exhaustion of the available food-supply, but to the accumulation of metabolic products which interfere with bacterial development. Such substances, however, are probably not, as they are sometimes assumed to be, complex cellular products peculiar to the cell producing them, but are simple acids or other substances due to molecular disintegration. It is, to say the least, questionable

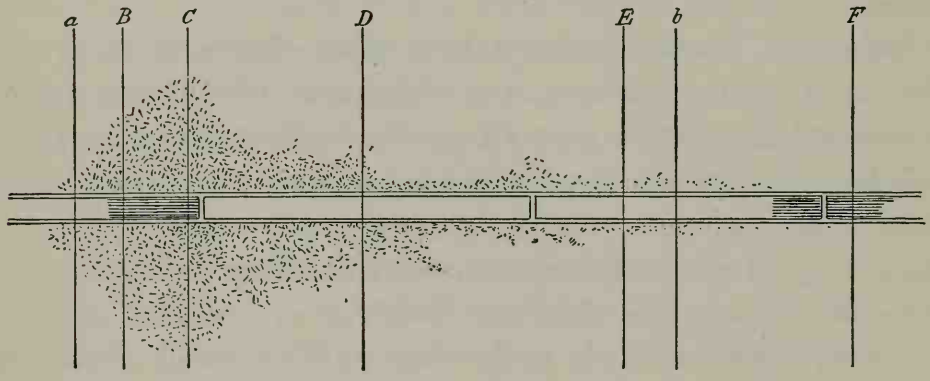


Fig. 21.—Bacteria gathered around alga, evolving oxygen (from Engelmann). Piece of cladophora with swarming bacteria in the microspectrum (gaslight). The chlorophyll grains which fill the cells very uniformly are omitted, and, instead, the absorption band between *B* and *C* and the tolerably pronounced band at the violet end between *E* and *F*, are indicated by shading.

whether specific inhibitory "autotoxins" are produced in bacterial cultures, although the matter needs further investigation.

In a state of nature single species or "pure cultures" of bacteria rarely have the field to themselves, the natural processes of decomposition and disintegration being carried on by a host of different microbes. Under open competition the growth of one species may be sometimes hindered, sometimes assisted, by products of associated or competing species. The favoring influence that aërobic bacteria and their products have upon the life of anaërobic bacteria has already been mentioned. The so-called "antagonism" between certain bacterial species is undoubtedly due to the nature of their chemical products. The presence of those microbes that produce acid by fermenting carbohydrates is, of course, peculiarly unfavorable

to microbes sensitive to acid. The chemical products of bacterial activity will be considered more at length in the following chapter.

Disinfectants and Antiseptics.—Chemical substances have been extensively employed for antisepsis and disinfection. An enormous number of such substances have been advocated for various purposes, but in many cases perfectly satisfactory disinfection is obtained with familiar and relatively simple chemical compounds. Most proprietary disinfectants are disproportionally expensive, and, owing to the lack of precise information as to their composition and strength, relatively untrustworthy.

A distinction is commonly made between antiseptics and germicides or disinfectants. An antiseptic substance is one that restrains or checks the development of bacteria, but does not destroy them. For example, a 1:300,000 solution of corrosive sublimate will prevent the development of anthrax spores, but a 1:1000 solution is necessary to kill them. The brine that is used in pickling meat has a strongly antiseptic action, but pathogenic bacteria have been known to retain their vitality in salt meat for long periods. Different methods and substances have been found adapted for different purposes.*

For the purpose of disinfecting rooms or apartments a gaseous substance is particularly useful. The custom of burning sulfur in infected rooms has the sanction of antiquity, and under certain conditions is reasonably effective. The sulfur dioxid (SO_2) that is formed when sulfur is burned is a germicide only in the presence of abundant moisture, sulfurous acid (H_2SO_3) being the active agent. Roughly speaking, about one-fifth of a pound of water should be volatilized for each pound of sulfur burned. "Exposure for eight hours to an atmosphere containing at least four volumes per cent. of this gas in the presence of moisture" is said to destroy all non-spore-bearing pathogenic bacteria. This requires the combustion of about 4 to 5 pounds of sulfur for every 1000 cubic feet. Not only bacteria, but mosquitos, fleas, and other possible insect carriers of pathogenic micro-organisms are destroyed, and this is one of the advantages of sulfur fumigation. The use of sulfur has

* The extensive use of heat for sterilizing or disinfecting instruments and surgical apparatus and for rendering bandages and dressings aseptic has been elsewhere considered.

the disadvantage that it lacks penetrative power and that it injures certain fabrics and materials. For the latter reason, especially, sulfur as a disinfectant of dwelling-houses has been largely superseded by formaldehyd (HCHO).

Formaldehyd, which is usually sold under the trade name of formalin, a 33 to 40 per cent. solution of the gas in water, is a more effective germicide than sulfur dioxid and has the great advantage that it does not damage books, paintings, and delicate fabrics, attack ordinary dyes, or act upon most metals. Like sulfur, it is efficacious only in the presence of moisture. According to McClintic* the humidity should not be lower than 60 per cent. and the temperature not less than 16° C. in order to obtain the best results. For practical purposes the gas may be generated in a variety of ways:

1. If the vapor of methyl alcohol be passed over a highly heated surface,—as, for example, over asbestos discs coated with finely divided platinum,—the partial oxidation that occurs gives rise to formaldehyd:

$$CH_3OH + O = HCHO + H_2O.$$

On this principle a number of lamps have been devised that have been used to some extent, but considerations of economy and of ease and efficiency of application have prevented a very general introduction of this type of generator.

2. If formalin is simply boiled, two molecules of formaldehyd unite, and a polymer, paraformaldehyd, is formed. The first effect of heating formalin, therefore, is to drive off water with a relatively small admixture of formaldehyd gas. If evaporation is continued, the boiling-point of the solution is raised and a temperature reached at which the polymer is broken up and formaldehyd is disengaged. The same end is reached more expeditiously if the formalin is superheated either in an autoclave under pressure, or in other special forms of apparatus. When steam under pressure is used, calcium chlorid (30 per cent.) or some other neutral salt is added to the formalin to prevent polymerization (Trillat system). Great penetration may be assured by the use of formaldehyd and dry heat in a partial vacuum. Many of the pieces of apparatus designed for liberating formaldehyd from formalin by heat are reasonably

* McClintic: Bull. 27, Hyg. Lab. and Mar. Hosp. Service, 1906.

effective, but are heavy and expensive. Simple heating of formalin in almost any kind of vessel will give good results if a liberal amount of formalin be used,—that is, 12 ounces for each 1000 cubic feet,—if some substance, as for example 10 per cent. of glycerin, which raises the boiling-point, be added, and if evaporation be not too rapid and be carried to a conclusion.

3. If the solid polymer of formaldehyd is heated, not ignited, formaldehyd is evolved. A lamp has been especially constructed for this purpose, and with the use of tablets or pastils of paraform affords an easy and effective means of disinfecting small rooms (Schering system).

4. Some formaldehyd is given off from the watery solution at ordinary room temperature. Use has been made of this in the method of spraying formalin upon sheets hung in a tightly sealed room. The gas, however, is evolved slowly under these conditions and in uncertain quantity, dependent upon many variables, such as temperature, amount of exposed surface, and other factors. Diffusion is necessarily poor.

5. Good results have been reported from the simple method of pouring formalin over crystals of potassium permanganate in an open vessel protected by some non-conductive material in such a way as to retain the heat. Sixteen ounces of formalin and six and three-fourths ounces of permanganate are recommended as a suitable proportion at temperatures of 16° C. and over; larger quantities of formalin are necessary if the temperature is below 16° C.

The disinfection of dejecta, sputum, and similar substances suspected of harboring disease germs may be effectively carried out by cremation or by boiling; but in practice a great variety of chemical substances, the ordinary "disinfectants" of commerce, are employed for this purpose. It should be remembered that, in accord with the modern theory of solutions and electrolytic dissociation, many solutions are chemically and biologically potent in proportion to the number of free ions or dissociated fragments of molecules that they contain. A comparison of the disinfecting power of the various metallic salts, for example, on the basis of percentage solutions would be misleading, since the degree of dissociation would differ in the several cases. A gram-molecule

or equimolecular solution must be employed in order to obtain comparable results. Unless dissociation takes place, solutions of metallic salts are practically without germicidal effect. A solution of mercuric chlorid in absolute alcohol has substantially no disinfecting power, but if water be added, the germicidal power of the solution increases proportionately to the amount of water added. Among the important points discovered by Krönig and Paul* in a now classic study of the action of disinfectants, it was shown that the disinfecting properties of the salt of a metal are due in large part to the specific action of the metallic ion, but also in some degree to the anion and to the undissociated part of the salt.

The number of chemical compounds used or recommended for purposes of disinfection is legion. Many compounds which are used depend for their effect upon the action of freshly liberated or nascent oxygen. One of them is potassium permanganate, which forms the basis of many of the patent disinfectants, but is expensive in proportion to its efficiency. Hydrogen peroxid (H_2O_2), another active oxidizing agent, is often used for the purpose of disinfecting the hands and for washing mucous surfaces. The commercial preparations of hydrogen peroxid (solutions of the gas in water) are liable to undergo deterioration unless carefully protected against light and air, and are hence apt to lack uniformity. Ozone is a powerful germicide and has been used with success in sterilizing water on a large scale, but cannot be advantageously generated and applied for ordinary purposes.

Among the metallic salts used for disinfection, corrosive sublimate (mercuric chlorid, bichlorid of mercury, $HgCl_2$) is one of the best known and most effective. In the presence of considerable quantities of organic matter, however, its use is totally inadmissible, for the reason that inert combinations between the Hg-ions and certain albuminous substances are formed, and a large part of the mercury thus rendered unavailable for action upon bacteria. In alkaline fluids such as many of the body fluids and pathologic exudates, oxids or hydroxids of mercury may be precipitated out, but the addition of a small quantity of common salt (NaCl) will prevent this. Corrosive sublimate is particularly serviceable in a standard solution, 1 : 1000, for the disinfection of the hands and for

* Krönig and Paul: Zeitschr. f. Hyg., 1897, 25, p. 1.

washing woodwork, floors, and furniture. It must be kept in mind that corrosive sublimate attacks metal, and is hence inapplicable for the disinfection of instruments and for use in plumbing fixtures.

Among the metallic salts that have been rather extensively used for disinfection are ferrous sulfate (copperas), zinc chlorid, and copper sulfate. The two former substances are of feeble germicidal power and are of little practical value except as deodorants. Copper sulfate has in recent years won a deserved reputation for destroying the microscopic algæ that sometimes impart offensive odors and tastes to public water-supplies. The death of the algæ in large bodies of water may be effected by as great a dilution as 1 : 1,000,000. Copper sulfate also possesses high bactericidal as well as algacidal power; according to a number of observers a dilution of 1 : 400,000 will kill typhoid bacilli in twenty-four hours, in water relatively free from organic matter, but other investigators doubt its practical availability for water disinfection on a large scale.

Some of the best-known and most efficient germicides are coal-tar products. Carbolic acid, or phenol (C_6H_5OH), is probably still the most generally used disinfectant, although of late years it has been to some extent supplanted by similar organic substances. When used in strong enough solution (5 per cent.) it will destroy all vegetative bacteria and most spores, even in the presence of considerable organic matter. Another merit of carbolic acid is the comparative permanence of its solutions. Cresol [$C_6H_4(CH_3)OH$] is somewhat like carbolic acid in composition, and is present in large amount in "crude carbolic acid"; it is almost insoluble in water. Tricresol is a mixture of orthocresol, metacresol, and paracresol; it dissolves in water in a 2.5 per cent. solution, which is about three times as powerful as carbolic acid. Creolin and lysol contain large amounts of the cresols, and some phenol, mixed with soap, which greatly facilitates the solution of cresol.

The sterilization of feces is advantageously carried out by the use of calcium hydroxid ($Ca(OH)_2$). In laboratory experiments 1 per cent. solution of freshly slaked lime in water has been found to kill nearly all pathogenic bacteria within a few hours. A 20 per cent. solution mixed with an equal part of the feces and urine of a typhoid patient will bring about complete disinfection within

an hour. The cheapness and high efficiency of freshly slaked lime render it the most useful of the common disinfectants for bowel discharges, the contents of privy vaults, and manure piles. Air-slaked lime, calcium carbonate, has no antiseptic value. A mixture of chlorid and hypochlorite of lime, the "bleaching powder" of commerce, is when fresh also very efficacious through the action of the chlorin which is liberated. The use of substances, like carbolic acid and chlorid of lime, that possess a pronounced and lingering odor, is open to the objection that the mere presence of the odor engenders a false sense of safety, regardless of the strength of the germicide used and the duration of its application.

Whatever be the aim or method of disinfection, it must be remembered that simple cleanliness is an indispensable adjunct, and that the use of hot water and soapsuds or soda solution is a powerful aid to the removal and destruction of disease germs. The germicidal action of sunlight in the presence of abundant oxygen supply should be utilized whenever possible.

Recommended Procedures for Disinfection.—In the case of a patient suffering from infectious disease different methods of disinfection are necessary according to the channel by which the disease germ leaves the body. In typhoid fever the urine and feces are likely to contain the specific germ; in consumption, the sputum.

The discharges from bowel and bladder should be received into a vessel containing a 5 per cent. solution of carbolic acid or fresh-prepared milk of lime made by adding one part of dry, freshly slaked lime to four parts of water. Slaked lime is prepared from quicklime by adding approximately one part of water to two parts of quicklime. The volume of the carbolic acid or milk of lime solution should be, at best, twice as great as the volume of the discharge. Thorough mixing and stirring are advisable, and solid masses of feces should be broken up. The mixture should stand for one hour before being thrown into the water-closet. The same treatment should be used for vomited material. The sputum from consumptive and pneumonic patients should be received in cups which contain a 5 per cent. carbolic acid solution or milk of lime. Paper cups may be used and burned with their contents. In the large number of other diseases in which the discharges from mouth and

nose are infectious, care must be taken to prevent the dissemination of germs by sneezing or coughing, and patients should be instructed on this point. Soiled handkerchiefs and cloths may be boiled after immersion in the carbolic acid solution for one hour. In general, bed-clothing, towels, napkins, and cotton underclothing may be treated in the same fashion. Blankets, woolen clothing, mattresses, etc., may be exposed to steam, hot air, or formaldehyd gas in one of the large forms of apparatus provided by boards of health, or if of slight value, burned.

Not only clothes, but all other articles coming into more or less direct contact with a patient or convalescent, and hence liable to be contaminated with epithelial scales or discharges from the mouth, nose, bladder, or bowels, must be carefully disinfected. Dishes and table implements should be provided for the exclusive use of the patient throughout his illness. After using they should be kept in hot water at or near the boiling-point for fifteen to twenty minutes. Articles of food—milk, for example—brought into the sick-room and remaining unused should be destroyed. Toys and books used by the patient and not of great value should be burned. Valuable books may be disinfected in a special formaldehyd chamber. Unopened books in book-cases whose surfaces only have been exposed will be satisfactorily disinfected in the course of the ordinary formaldehyd room disinfection. Woodwork and wooden furniture may be thoroughly washed with corrosive sublimate, 1 : 1000. Upholstered furniture, rugs, and carpets, if allowed to remain in the room at all, are difficult to disinfect, and, especially if soiled with discharges, need to be treated in a special formaldehyd chamber. The hands of the patient and of nurses and attendants need particular attention. After a thorough cleansing with 2 per cent. solution of carbolic acid or a 1 : 1000 solution of mercuric chlorid they should be washed with soap and water. This should always be done before eating. Parts of the body that become soiled with discharges should be immediately cleansed in the same way.

Room disinfection may be carried out with formaldehyd gas generated in one of the ways already specified. The room must be tightly sealed, a temperature of at least 10° C. (50° F.) must be maintained, and the atmosphere must contain at least 75 per cent. of moisture. Sleeping-cars, ambulances, and the like may be disinfected by the same means.

For performing surgical operations thoroughly cleansed instruments may be sterilized by boiling for one minute in a 1 per cent. soda solution. Rubber gloves for the hands of the operator and assistants are now generally used in surgical operations and may be sterilized in the same way. The skin of the patient may be first washed scrupulously with alcohol and then with a 1:1000 solution of mercuric chlorid. Bandages, towels, gauze, surgeons' gowns and caps are usually sterilized by heat. Syringes may be sterilized by boiling for fifteen to twenty minutes, preferably in water to which 2 per cent. of soda is added.

CHAPTER V

THE EFFECTS PRODUCED BY BACTERIAL GROWTH

In the preceding chapter it has been shown that bacteria may be greatly modified in all their functional activities by the character of their surroundings. They are not, however, mere passive victims of their environment. The influence exerted by the higher forms of life upon surrounding objects is often impressive, and bacteria also can react upon their environment in a direct and sometimes surprising fashion. Relatively slight physical and chemical changes in bacterial surroundings may give rise to a remarkable and profound disturbance of the surroundings themselves. The rapid invasion of the animal body by bacteria and the resultant putrefactive change which takes place soon after death is a familiar instance. The infection of the body of the fowl by the anthrax bacillus, which has no effect upon the normal animal, but gains a foothold and effects injury when the temperature of the fowl is lowered only a few degrees below the normal, affords another example. The variations in the nature of the bacterial products due to slight changes in nutrient media offer innumerable illustrations of the reactions of bacteria upon their surroundings in response to relatively insignificant environmental changes.

Physical Effects.—Both heat and light may be generated by bacterial growth. As would be expected from chemical considerations, the temperature of organic substances undergoing bacterial decomposition is frequently raised high above that of the surroundings. The heating of manure piles or of damp hay is often classed as a bacterial phenomenon. It is even thought that some cases of "spontaneous combustion" should be attributed to the agency of the thermogenic bacteria, and that although the train of events leading to the actual bursting into flame is not fully understood, bacteria play a part in the initial stages of the process. Boekhout and de Vries* maintain that the self-heating of the hay is of a

* Boekhout and de Vries: Centralbl. f. Bakt., II, 1904, 12, p. 675; 1908, 21, p. 398.

purely chemical nature. Miehe,* in an exhaustive monograph on the subject, adduces strong evidence of the thermogenic power of certain micro-organisms. The latest observations, however, support the view that the heating process is due to chemical reaction unaided by bacterial activity.

The phosphorescence sometimes observed upon decaying fish and meat is due to the growth of light-producing bacteria. Sodium chlorid and magnesium chlorid favor the growth of these phosphorescent bacteria, and one or other of these salts is essential to the production of light. Aërobic conditions are absolutely necessary for photogenesis. The photogenic bacteria are found most commonly, though by no means exclusively, in sea-water and upon the bodies of marine animals. As many as 28 different species have been enumerated. The light generated by active cultures of these organisms is considerable; photographs of cultures have been taken by their own illumination.† It is supposed that a substance in the living cell—photogen—is responsible for the light phenomena. Photogen, like zymase, is closely bound to the cell protoplasm; unlike the former, photogen has not yet been freed by pressure and filtration from the living cell.

Chemical Products.—From a physiologic standpoint the substances produced by bacterial life and activity may be divided conveniently into four classes: (1) The *secretions*, or those substances which subserve some purposeful end in the cell-economy; these may be retained inside the cell or they may pass out into the surrounding medium. (2) The *excretions*, or those substances that are ejected because useless to the organism: the ashes of cell-metabolism. (3) The *disintegration products*, or those bodies that are produced by the breaking-down of food substances; their nature is determined partly by the chemical structure of the nutrient, partly by the specific bacteria concerned in the disintegration; some of the most conspicuous, if not the most important, of bacterial products belong to this class; enzyme action is largely responsible for their existence. (4) The true *cell-substance*. Under this head may properly be included the protoplasm itself, substances in the

* Miehe: "Die Selbsterhitzung des Heus," Jena, 1907, p. 127.

† See especially Molisch, H.: "Leuchtende Pflanzen," Jena, 1904, pp. 121–151.

early stages of assimilation that are on the way to become protoplasm, and substances that are being broken down but have not reached the stage where they are cast out of the cell.

Even on the basis of such a classification it is not always easy to assign to any given bacterial product its proper significance. Enzymes can readily be placed in the class of secretions, but the physiologic meaning of bacterial pigments, for instance, is obscure. It is variously held that the pigments are disintegration products, that they are excretions, or even that they are secretions.

The Production of Pigment.—Most bacterial cells do not contain pigment, and a mass of bacteria—an agar culture of B. typhosus, for example—has to the naked eye a muddy gray tint. Some kinds of bacteria, however, in the course of their growth, give rise to colored substances, often of brilliant hue. Some pigments occur in solution; others in the form of granules outside of the cell in the nutrient substratum. Practically all colors of the spectrum are represented: violet, indigo, blue (B. violaceus, B. janthinus, B. cyanogenes, B. pyocyaneus); green (B. fluorescens); yellow (Staphylococcus aureus, Sarcina lutea); orange (Sarcina aurantiaca), and red (B. prodigiosus). Great variation may occur in the amount and character of the pigment produced by one and the same species; cultivation on the ordinary media often occasions the temporary or permanent loss of chromogenic power (B. violaceus), and growth at an unusual temperature may have a similar effect (B. prodigiosus at 37°). Some species that are not usually regarded as chromogenic may give rise to colored sports (*e.g.*, B. diphtheriæ, Hill). As a rule, oxygen is indispensable to pigment production, and most chromogenic species yield no trace of pigment when grown under anaërobic conditions. Spirillum rubrum, however, which grows well in the presence of oxygen, is said to form its red pigment only in oxygen-free media. In the case of some chromogens the presence of certain chemical compounds or elements in the nutrient media is essential to, or greatly favors, pigment production. Thus phosphates and sulfates have been found necessary for the production of pyocyanin by B. pyocyaneus, and sodium tartrate has been shown to favor the production of pigment by B. prodigiosus. Carbohydrate media (potato, rice, and wheat starch) often lead to a particularly brilliant chromogenesis. Antiseptics may check or altogether

inhibit pigment production. The bacterial pigments are chemically of diverse nature. Many of the red and yellow pigments are insoluble in water, but soluble in alcohol, ether, and chloroform. Others, like the fluorescent pigment, are soluble in water, but not in ether or strong alcohol. Some, and possibly the majority, are chemically related to the lipochromes, a group of fatty pigments widely distributed throughout the plant and animal kingdom. The reactions of others suggest an affinity to certain anilin dyes, such as fuchsin.

The relation of the bacterial pigments to the physiology of the individual cell is a debated point. It is held by some that the pigments are mere by-products that have no particular meaning for the organisms forming them, and that their formation is an incidental, and not an essential, feature of the cell-metabolism. As regards the majority of bacterial pigments, there is much to support this position. It is maintained by others, however, that at least some pigments enter into a loose combination with oxygen, analogous to the union effected by hemoglobin, and that under certain circumstances oxygen may be liberated. It has been suggested, further, that the pigments serve to protect the bacteria producing them from the action of light, but experimental evidence is against this view.

Enzymes* and Fermentation Products.—It is well established that many of the chemical effects wrought by bacteria, as by other living cells, are due, not to the direct action of the protoplasm, but to the intervention of soluble ferments or enzymes. Probably the majority of the disintegrative processes in which bacteria are concerned are carried on by means of these powerful protoplasmic auxiliaries. In many cases the enzymes diffuse out from the cell and exert their effect upon the ambient substances, as do, for example, the gelatinases or gelatin-liquefying enzymes; in others the enzyme action occurs within the cell and the products pass out. The zymase or alcohol-producing enzyme of the yeast-cell apparently does not diffuse out, but acts upon sugar within the cell, the resulting alcohol and carbon dioxid being ejected. The difference between enzyme action within and without the cell would not seem to be a fundamental one.

* See Fuhrmann: "Vorlesungen über Bakterienenzyme," Jena, 1907.

It is in accord with the great adaptability shown by bacteria in their utilization of various food-substances that the list of enzymes known to be secreted by different species is a long one. Probably all classes of enzymes are represented among bacterial products, although in some cases where there is reason to suspect enzyme action no enzyme has yet been demonstrated. Some of the changes in nutrient media that are most relied upon as differentiation marks are effects produced by enzymes, such as the liquefaction of gelatin, the precipitation of casein, the dissolving of casein, and the inversion of sugar. A single form of micro-organism may secrete more than one kind of enzyme, and some species are known to give rise to a large number. Different kinds of enzymes are formed under the influence of different conditions of life, the nature of the nutrient substratum being especially determinative. The presence of a particular carbohydrate, for example, may stimulate a bacterial species to produce a hydrolytic enzyme, which under other circumstances is not found among the products of that species.

The term fermentation has been used, and to some extent is still used, to express various conceptions. A sharp distinction between changes produced by the living cell and changes produced by enzyme action is no longer tenable, since many of the effects once ascribed to "living ferments" have been shown to be directly attributable to cell-secreted enzymes. The discovery of the alcohol-producing enzyme, zymase, has removed almost the last excuse for limiting the term fermentation to direct protoplasmic interference. More recently the nature of the substances acted upon has been made the basis of distinction. The tendency at present is to limit the term fermentation to the disintegration of carbohydrate substances, and there are some who would go so far as to consider as true fermentations only those carbohydrate decompositions in which gas is produced, a virtual reversion to the old etymologic signification (*fervere*, to boil). In ordinary descriptions it is customary to state that B. typhosus, for example, does not ferment lactose, that Staphylococcus aureus ferments lactose with production of acid, and that B. coli ferments lactose with production of acid and gas. Proteolytic action is not usually denoted as fermentation, though logically the putrefaction of proteid substances by bacterial

agency falls in the same category with the decomposition of sugar by the action of the yeast-cell.

The large group of disintegrative products can only be briefly touched upon here. A considerable portion of this book is devoted to the description of the various activities and products of important microbes, and the reader will soon become aware that a notable share of the interest that attaches to certain species is due to the nature of the chemical changes wrought by them in the surrounding food-substances.

The "Iron Bacteria."—Among the trichomycetes (p. 411) or filamentous bacteria are found some varieties especially characterized by deposits of iron oxid in the sheath. The best-known of these organisms is the widely spread Crenothrix, which sometimes grows in the conduits of certain public water supplies, where it forms unpleasant-looking, brownish, flocculent masses. The frequent appearance of these latter in tap-water gives rise to consternation among the water consumers, as in the famous "water calamities" in Berlin, Lille, Rotterdam, and other places. There is no evidence that Crenothrix is directly harmful.

Winogradsky, explaining the presence of iron in the sheath by the oxidation of carbonate of iron in the cell-protoplasm of Crenothrix, asserted that the presence of some iron salt was indispensable to the growth of the micro-organism, and attached great significance to the physiologic activity of the iron bacteria in causing the deposit of iron from solution and the consequent formation of great beds of mineral iron in the earth's crust. Molisch, on the other hand, found experimentally that certain of the so-called iron bacteria grew freely in an iron-free solution. The latter author concluded from his investigations of iron ore from various sources that these micro-organisms were by no means universally concerned in the deposition of iron on a large scale, but that under some conditions they might play an important part in the process. Manganese has also been found in the sheath of Crenothrix in even larger quantities than iron (Jackson). The complete physiology of these interesting organisms needs further elucidation.

The "Sulfur Bacteria."—Sulfur, like nitrogen, is an essential constituent of living matter. When organic matter is decom-

posed by bacteria, sulfuretted hydrogen (H_2S) is one of the usual disintegration products. If anaërobic conditions prevail or if the medium is rich in sulfur compounds, as for instance is the case with the yolk of eggs, the odor of H_2S is usually plainly perceptible, and has come to be recognized as one of the most familiar signs of decomposition. The sulfuretted hydrogen may arise either from the splitting off of H_2S groups already present in the molecule or from the reducing action of the bacteria upon the protein substance. Sulfuretted hydrogen may also be formed by the reduction of inorganic sulfur compounds, such as sulfates, sulfites, and thiosulfates. Many different kinds of bacteria, including most of the common laboratory organisms, are able to generate sulfuretted hydrogen from protein bodies. The reduction of sulfates, however, seems to be a quality less widely shared and is not possessed, for example, by such bacteria as Bacillus coli, which reduces nitrates vigorously. Beijerinck has isolated a special micro-organism, Spirillum desulfuricans, which he regards as the peculiar organism of sulfur reduction.

The direct physiologic opposite of these reducing bacteria are the *sulfur bacteria* proper, which are able to exert a strongly oxidizing action upon sulfuretted hydrogen. These organisms are found in the water of sulfur springs, in sewage-laden streams, in swamps where masses of vegetable matter are slowly decomposing, and, in fact, wherever an abundance of sulfuretted hydrogen is being liberated. Two genera are especially recognized: *Beggiatoa* and *Thiothrix*. The former is a long cylindric filament possessed of the power of active movement and showing a close morphologic resemblance to the blue-green alga Oscillaria. Thiothrix is differentiated from Beggiatoa by its lack of motility, by the possession of a sheath, and by the formation of so-called conidia or spores. A group of non-filamentous, colorless sulfur bacteria also exists (Thiophysa, etc.), but has thus far been little investigated. The so-called red or purple sulfur bacteria are peculiarly interesting. These organisms were observed in 1826 by Ehrenberg, and in recent years have been studied especially by Winogradsky, who has placed them in a family by themselves, called the Rhodobacteriaceæ. They are found especially in situations where a vigorous reduction of sulfates is taking place and where, con-

sequently, sulfuretted hydrogen is present in great abundance. The pigment which imparts the characteristic color to these organisms gives some of the reactions of the lipochromes, but little is definitely known about its composition. Unlike the unpigmented sulfur bacteria, which are completely indifferent to light, the purple bacteria gather by preference on the light side of an aquarium. The view of Engelmann, however, that the pigment is similar to chlorophyl and that the purple bacteria, like the green plants, give off oxygen in the sunshine, has not been confirmed.

The physiology of the group of sulfur bacteria is unlike that of any other living organisms, and they deserve to be set apart, as Winogradsky has proposed, as an independent physiologic group. The true sulfur bacteria all contain in their protoplasm highly refractive inclusions which have been found to be amorphous sulfur. The presence of sulfur in the cell is undoubtedly connected with the fact that the organisms are only found abundantly in waters containing sulfuretted hydrogen. The discovery of the full physiologic significance of these findings has been largely the work of Winogradsky. By the oxidation of sulfuretted hydrogen to sulfuric acid, which is, of course, at once neutralized by the carbonates present, the sulfur bacteria obtain the energy necessary for their development. Sulfuretted hydrogen, in a word, is their principal food. According to Winogradsky, the single Beggiatoa threads use in a day two to four times their own weight of H_2S. The sulfur in the cell-protoplasm is to be looked upon as an intermediate stage in the oxidation process. The course of the reaction may be indicated by the following equations:

$$(1)\quad 2H_2S + O_2 = 2H_2O + S_2.$$
$$(2)\quad S_2 + 3O_2 = 2H_2O + 2H_2SO_4.$$

That sulfuretted hydrogen is indispensable for the continued activity of these organisms and is for them the sole available source of energy is inferred from the fact that if it is not accessible the store of sulfur in the cells quickly disappears (in twenty-four to forty-eight hours) and the bacteria apparently then die from starvation. It seems probable that the sulfur bacteria require no organic substances for their development, but that, like the nitrite bacteria (p. 504), they can subsist on a purely mineral diet. For these organisms, therefore, sulfur in its combination with

hydrogen seems to have the same physiologic value that carbon in its hydrogen compounds has for most other bacteria.

The Production of Acid and Alkali.—The production of acid and alkali by bacteria is one manifestation of enzyme action. The occurrence of acid production is so commonly used as a means of special differentiation that it is convenient to consider this topic separately. In general it may be said that an acid reaction is caused by the fermentation of some sugar, glycerin, or similar body present in the nutrient medium. The muscle-sugar in nutrient broth made from fresh meat, the lactose in milk and whey, and other sugars naturally present in, or artificially introduced into, various culture-media, are usually responsible for the occurrence of an acid reaction in the medium as a sequence of bacterial growth. In a word, the production of acid by a given species is due to its ability to break up some chemical substance in such a way that hydrogen ions are liberated. Thus the colon bacillus ferments lactose and saccharose, and in consequence provokes an acid fermentation in media containing these carbohydrates, while the typhoid bacillus is unable to effect this change. In a peptone-mannite solution, on the other hand, the typhoid bacillus produces acid in twenty hours at 37°, while B. coli leaves the original reaction unaltered.* The power of acid production, or, more narrowly, the ability to ferment certain sugars, is one of the more constant physiologic characteristics of bacteria, and has been used advantageously to distinguish closely allied organisms, notably in the groups of paratyphoid and dysentery bacilli.

Carbohydrates are not the only substances the breaking-down of which is accompanied by an acid reaction. The liquefaction of gelatin by bacteria gives rise to a noteworthy increase in the acidity of the medium, due to the formation of amino-acids.

Alkali production is sometimes declared to be more intimately bound up with the constructive (anabolic) side of bacterial metabolism than with its destructive aspect, but the real difference between alkali and acid production lies in the nature of the substances attacked. In sugar-free nutrient broth the majority of bacterial species produce an alkaline reaction due to the formation of ammonia. This is more marked with some kinds than with others. B. pyocy-

* Capaldi and Proskauer: Ztschr. f. Hyg., 1896, 23, p. 452.

aneus, B. suipestifer, and B. diphtheriæ are among the especially vigorous producers of alkaline substances. The alkalinity of a culture undoubtedly depends in most cases upon the fact that the food-substances are disintegrated by the bacterial cells or their enzymes in such a way as to yield bodies that give rise to free hydroxyl ions. Protein substances, as a rule, break up in this way, while carbohydrates, when they are attacked at all, give rise to acids.

Putrefactive Products.—The decomposition of nitrogenous compounds constitutes a striking feature of bacterial activity, and one that has always claimed attention. One reason for the conspicuous character of protein decomposition, apart from the profound modifications that are observed to occur in the dead animal or plant body, is the frequent production of malodorous compounds like mercaptan and skatol, which obtrusively betray the neighborhood of decaying nitrogenous substances. The gases arising from the disintegration of proteids are numerous and varied. Ammonia, carbon dioxid, hydrogen, marsh-gas, sulfuretted hydrogen, and nitrogen are among the more common gases generated by bacterial action. A variety of volatile compounds, amids, peptones, and aromatic bodies, are also formed in the course of the complicated processes of putrefaction. The substances formed under anaërobic conditions differ materially from those formed in the presence of oxygen, it being well known, for example, that anaërobic decompositions are peculiarly apt to be accompanied by the evolution of offensive gases. Many writers believe* that only obligatory anaërobes, and not all of those, are able to bring about putrefactive changes in native proteins. In general, it may be said that the action of bacteria upon proteins is very similar to the action of tryptic digestion, and results first in the formation of albumoses and peptones, which are then broken up into amino-acids. The amino-acids themselves are excellent nutrients for bacteria, as shown by Czapek,† and are split both by the elimination of ammonia and by the splitting off of carbon dioxid. Free fatty acids, aromatic acids, and certain ptomains, cadaverin and putrescin, are among the further products of decomposition.

* See Rettger: Jour. Biol. Chem., 1908, 4, p. 45.

† Czapek: Hofmeister's Beitr., 1902, 1, p. 538.

Indol is a substance which has assumed importance as an aid to the differentiation of bacterial species. It is one of the final products of the decomposition of albuminous bodies, belongs to the aromatic series (C_8H_7N), and is characterized by a peculiar odor. It gives a red color reaction when strong nitric or sulfuric acid and a 0.01 per cent. solution of sodium nitrite are added drop by drop to a solution containing it, as, for instance, a peptone culture of an indol-producing organism. It also produces a cherry-red color when an acid solution of dimethylamidobenzaldehyd is added to an indol solution; this is a more delicate test than the former.

The Relation of Bacteria to Food Assimilation by Higher Forms of Life.—The question whether the bacteria usually so abundantly present in the alimentary tract of man and the higher animals play a useful or a harmful part has been the theme of considerable speculation and some experimentation. Nuttall and Thierfelder, who were among the first experimenters in this field, succeeded in raising aseptically guinea-pigs that had been removed by Cesarean section from the body of the mother. The young animals, which were fed on sterile milk, lived for as long as ten days after birth and their weight increased as much as 28 grams. From such facts these investigators concluded that the presence of bacteria in the digestive tract is not indispensable for the life of the guinea-pig; by analogy they infer that the same would be true for the other higher animals and for man. Schottelius* vigorously combats this view on the basis of his own experience in raising sterile chicks. In the conduct of these experiments, the egg-shells were carefully washed with corrosive sublimate, which was then completely removed by chemic neutralization; this procedure is not injurious, since control eggs yield perfectly normal chicks. Throughout Schottelius' experiments complete bacterial tests of the food, air, water, and dejections were made at the beginning and the close of each series. The bacteria-free chicks were apparently hungrier than the others and ate more greedily, but in spite of this fact always lost weight and usually died before reaching the thirtieth day. When some of the sterile chicks were separated from the others and given

* Schottelius: Arch. f. Hyg., 1902, 42, p. 48, and 1908, 67, p. 177.

food contaminated with fresh fowl droppings, they always throve better than the control chicks and usually gained weight and grew to maturity. When a pure culture of a variety of Bacillus coli was used to inoculate the food equally good results were obtained. A mixture of air-cocci with the food was not so favorable. From these results Schottelius concludes that the bacteria normally present in the digestive tract have a marked beneficial influence and are in reality necessary to the life of the higher animals. Schottelius further maintains that the increase in weight of the guinea-pigs in Nuttall and Thierfelder's experiments was due not to a genuine tissue construction, but to the presence of coagulated and undigested milk in the alimentary canal.

Ptomains and Toxins.—For evident reasons a high degree of interest attaches to the poisonous products of bacteria. As might be anticipated, these products differ in respect to their origin and physiologic significance.

It may happen during the course of the decomposition of organic substances that toxic bodies are produced simply as a consequence of the mode of disintegration of the protein molecule. Such poisonous products of decomposition, for example, are a few substances belonging to the group of alkaloid-like bodies known as *ptomains*, basic compounds characterized by a more or less definite chemical composition. Investigators have supposed that in the decomposition of meat, fish, cheese, and the like, poisonous ptomains are formed in such quantities that the ingestion of partly decayed food can cause acute poisoning. It is possible that cases of "ptomain poisoning" in man due to ingestion of ptomains or to their formation within the intestine sometimes occur, but there is no doubt that such cases, if they occur at all, are very rare. Many of the epidemics of "meat poisoning," etc., are now known to be due to infection with specific micro-organisms, rather than to the action of a formed poison. It still remains to be proved that the ptomains play any really important part either in isolated cases or in outbreaks of food-poisoning, or in the so-called gastro-intestinal auto-intoxications.

The nature of the poisons produced by bacteria in the living body has been much debated. There is reason to think that they are not simple disintegration products, but are more closely related to the life of the bacterial cell. At one time the specific bacterial

poisons were believed to belong to the class of ptomains just referred to, but this view was abandoned when it was shown that the ptomains apparently generated by certain pathogenic bacteria were not able to reproduce the appropriate symptom-complex of any disease, and did not correspond in other respects with the toxicologic requirements. There is, furthermore, some reason to look upon at least a portion of the ptomains isolated from decomposing substances and from bacterial cultures as secondary products due to too heroic methods of chemical manipulation, and not as the primary products of bacterial activity.

The opinion that the specific bacterial toxins belong to the class of proteins or albuminous substances has found some support. It is possible by various procedures to extract from the cultures of certain pathogenic microbes substances of a protein nature which are more or less toxic, but it is by no means certain that these are the pure substances to which bacterial action must be attributed. In fact, the substance that gives the positive protein test may be merely an impurity adhering to the true toxin. One of the potent vegetable poisons, ricin, long regarded as a typical toxalbumin, has been obtained by Jacoby * in a form that possesses the characteristically active qualities of ricin, but does not answer to the protein tests.

The true bacterial *toxins*, in the modern acceptation of the term, are specific poisonous metabolic products of bacteria. They are of completely unknown chemical structure, are probably colloidal, are extraordinarily labile, and display great sensitiveness toward slight heating. In many respects they are closely analogous to the enzymes. One of the most characteristic qualities of the true toxin is its ability to evoke the formation of an antibody, an antitoxin, when injected into the body of a suitable animal species. The potency of the bacterial toxins is extraordinary, and far surpasses that of any other known poison.

Minimal fatal dose of	atropin for adult man	130 mg
" " " "	strychnin for adult man	30 to 40 mg.
" " " "	cobra venom for adult man	4.375 mg.
" " " "	tetanus toxin for adult man	less than 0.23 mg.

Some bacteria, as the tetanus bacillus, are able to produce their specific toxin in the animal body; others, as B. botulinus (p. 330),

* Jacoby: Arch. Exp. Path., 1901, 46, p. 28.

form their toxin, so far as known, only in organic substances outside of the living body.

The constitution of the toxin molecule has been the subject of much study, especially by Ehrlich and his coadjutors. Elaborate experiments have shown that the toxin is a complex substance. To take a specific illustration, it is found that broth in which the diphtheria bacillus has grown loses, on standing, a certain part of its toxicity, but retains undiminished its affinity for diphtheria antitoxin. In other words, there is no constant relation between the toxic strength of the broth and the amount of the broth that is neutralized by a given quantity of diphtheria antitoxin. This is held to indicate that the toxin is not a simple chemical unit, but is composed of two portions, distinguished by their different stability. Exposure to light and air destroys the toxic portion of the toxin-complex, but leaves the combining portion intact. Hence a toxin is supposed to consist of two portions: a combining or *haptophore* atom-group, which is able to unite with the corresponding antitoxin, and a specific *toxophore* atom-group, to which the poisonous action is due. Those modifications of the toxin-complex from which the toxophore portion has more or less completely disappeared, while the haptophore group persists, are designated as *toxoids*.

The name *toxon* has been given to a poisonous product of bacterial growth possessing the same haptophore group as the toxin, but of far less avidity. The toxophore group of the diphtheria toxon is conceived as different from the toxophore group of the diphtheria toxin, in that it is incapable of producing acute effects, cutaneous necrosis, and death, but, on the other hand, is responsible for the characteristic late diphtheria paralysis. Analysis of the phenomena attending the neutralization of toxins and antitoxins of various strengths has led Ehrlich to a belief in the existence in toxic broth of a variety of toxic bodies possessing varying degrees of avidity and toxicity. These are the so-called prototoxins, deuterotoxins, prototoxoids, etc. It has been urged against this view by Arrhenius and Madsen,* on physicochemical grounds, that the behavior of mixtures of toxin and antitoxin can be explained by reference to the law of mass-action enunciated by Guldberg and Waage. On

* Arrhenius and Madsen: Zeit. f. physik. Chemie, 1903, 44, p. 7.

the latter hypothesis it would be superfluous to assume the existence of different components, and sufficient to regard the toxin as a single uniform substance possessed of a weak affinity for its antitoxin. Further researches have shown that it is not possible to bring the reaction of toxin and antitoxin within the law of mass-action, and that the relations of these two bodies to one another are much more complicated than would be expected if they were simple crystalloidal substances. On the other hand, certain striking analogies have been shown to exist between the behavior of toxins and the behavior of colloidal substances, and it seems possible that the phenomena seen in mixtures of toxin and antitoxin may be due to a reaction between two colloids. Grassberger and Schattenfroh * have found that the poison of the bacillus of symptomatic anthrax is free from toxoids and toxons, but that, nevertheless, toxin and antitoxin mixtures unite in variable proportions.

All of the foregoing statements, and practically all that is known of the bacterial toxins, relate to the so-called *extracellular toxins*, that is, to those toxins of which tetanotoxin and diphtheria toxin are the types, which diffuse through the bacterial cell-wall during life and are found in the fluid culture-media in which the bacteria are grown. In broth cultures of the cholera spirillum, typhoid bacillus, and most other pathogenic organisms no such soluble toxins are found, and it has been assumed that in these cases the specific toxic substances are *endotoxins* which remain wholly or in great part within the cell during the life of the microbe, and are liberated only through cell disintegration at death or in consequence of mechanical or chemical treatment. The intracellular toxins have been compared in this respect to the zymase of the yeast-cell, which is a typical endoenzyme, and is not found in the culture-medium in which the yeast-cell is living. Attempts to extract *specific* endotoxins from triturated or frozen cells have, however, signally failed. An alternative hypothesis with much in its favor conceives that those pathogenic bacteria which do not generate toxins in ordinary culture-media do produce them when growing in the animal body. On this conception the failure to obtain toxins from cultures of

*Grassberger and Schattenfroh: "Ueber die Beziehungen von Toxin und Antitozin," Leipzig u. Wien, 1904.

the typhoid bacillus, the anthrax bacillus, and most pathogenic microbes is to be attributed to the fact that the common culture-media are unsuitable for the generation of the peculiar toxic secretions.

In addition to the existence in or production by certain kinds of bacteria of poisonous bodies which reproduce with more or less fidelity the characteristic symptoms and lesions of a specific disease, the cell-substance of all bacteria contains compounds, presumably of a protein nature, which prove injurious when introduced into the animal body. These bacterial proteins, which may be extracted by maceration or high pressure, illustrate in their action the baneful effect generally observed when alien protein substances are incorporated into the animal body. The poisonous effect of blood derived from one animal when transfused into a different species is a well-known instance of the injurious action of foreign protein, as has been amply demonstrated in the recent studies on hemolysis. The effects provoked by injecting bacterial proteins from the non-pathogenic as well as the pathogenic species consist, broadly speaking, in localized inflammation, aseptic pus-formation and necrosis, and also in certain constitutional symptoms, such as fever, lassitude, and headache.

Not only do bacterial proteins cause certain general effects, but inoculation of dead bacteria can give rise to specific tissue changes. The injection of tubercle bacilli killed by heat causes the formation of characteristic tubercle nodules in susceptible animals.

Substances possessing the closest resemblance to the bacterial toxins occur in the seeds of some of the higher plants and in the secretions of certain animals. Among the best known of the vegetable toxins (phytotoxins) are ricin (from the castor-oil bean, *Ricinus communis*), abrin (from the jequirity bean, *Abrus precatorius*), and the similar substances, crotin and robin. These poisons, like the bacterial toxins, are exceedingly potent. It is estimated that one gram of ricin, properly diluted, is sufficient to cause the death of 1,500,000 guinea-pigs. Ricin not only exerts a strongly toxic effect upon the tissues at the seat of inoculation, but also causes agglutination of the erythrocytes. After injection an incubation period is observed, as in case of the bacterial toxins.

By use of the same methods as with the bacterial toxins, antiricin and the other corresponding antibodies may be produced, and the existence of haptophore and toxophore groups in these poisons is inferred on the same grounds. Specific toxic bodies are found in the blood and secretions of a number of animals (zoötoxins). Snake venom and the poisons of scorpions and spiders, as well as an actively poisonous substance present in eel-blood, are more or less familiar examples. The chemical behavior and physiologic action of these poisons are strikingly similar to those of the true bacterial toxins. The snake venins owe their power to a variety of active principles: (1) hemagglutinin, (2) hemorrhagin (present especially in rattlesnake venom), (3) hemolysin, and (4) neurotoxin. Antibodies have been successfully produced against these several toxic bodies. The action of the venins and antivenins is more complicated than that of the bacterial toxins.

CHAPTER VI

THE CLASSIFICATION OF BACTERIA

Bacteria are minute unicellular organisms generally classed as plants rather than as animals. It is well known that any strict dividing-line between animals and plants is an entirely arbitrary one, and that there is no general argument among naturalists respecting what shall constitute a determinative plant or animal characteristic. As regards the simplest forms of life, the power of independent movement has been perhaps most widely advocated as a mark, admittedly arbitrary, of animal nature. Such a distinction would cause diatoms to be ranked as animals and some sporozoa as plants. Many bacteria, as is well known, are actively motile. It has already been pointed out that the cell-wall of bacteria, unlike that of plant cells in general, is not composed of cellulose. On the other hand, transition forms connect the typical bacteria with certain lower algæ and fungi universally recognized as true plants. Some of the filamentous blue-green algæ, of which the genus Oscillaria is an example, are closely related to undoubted bacteria, and this fact among others has disposed naturalists to place bacteria with the plants. As a matter of fact, little importance is now attached to such questions, since there is every reason to suppose that all living organisms are fundamentally alike and originated from a common state. It is among the lowest forms of life that divergences between animals and plants melt away, and organisms possessed of characteristics of both groups are found.

Bacteria, therefore, occupy an intermediate position between the vegetable and animal kingdom, and it is largely considerations of convention and convenience that place them among the plants. Since they possess no chlorophyl, they must be regarded as fungi. From their method of vegetable multiplication by simple fission they are known as fission-fungi or *Schizomycetes* (Ger., *Spaltpilzen*).

Within the group of bacteria themselves classification is, for practical purposes, especially important.

In general, the classification of living organisms is based on morphologic characters which are, broadly speaking, less liable to

sudden change and more apt to coincide with relationship by descent than with physiologic characters. Walking mammals (horses), flying mammals (bats), and swimming mammals (whales) are more fundamentally alike than flying mammals and flying insects. Both the wing of a butterfly and the wing of a bird serve the purpose of flight, but structurally the two kinds of wings are far apart, and the animals themselves belong to widely separated branches of the animal kingdom.

Bacteria, however, are of such minute size and the observable differences in structure are so slight that any classification grounded on morphologic characters meets with many difficulties. Microorganisms that resemble one another very closely in appearance may differ radically in respect to the chemical changes to which they give rise, or to the pathologic processes that they evoke. Since these pathologic processes and chemical changes are of great practical importance, bacteriologists have come to lay considerable stress upon physiologic qualities. There can be no valid objection to such a practice. The modes of nutrition of bacteria and the products of their growth must give a more correct insight into fundamental internal structure than can simple external form, especially for organisms that lie on the limit of invisibility.

A promising beginning in classifying bacteria on a physiologic basis has been made by Jensen.* On the basis of source of nutrition the following chief groups are distinguished:

(1) Bacteria which, like the green plants, need neither organic carbon nor organic nitrogen. These so-called autotrophic bacteria can build up both carbohydrates and proteins out of carbon dioxid and inorganic salts.

(2) Bacteria which need organic carbon compounds, but can dispense with organic nitrogen. These bacteria are able to synthesize protein substances out of carbohydrates (or organic acids), and ammonia, nitrogen, or nitrates.

(3) Bacteria which, like the higher animals, require both organic carbon and organic nitrogen compounds. These bacteria cannot accomplish either carbohydrate or protein synthesis out of inorganic substances. Upon such principles Jensen has constructed an outline of a system of classification which probably gives a

* Centralbl. f. Bakt., II, 1909, 22, p. 305.

truer picture of the natural relationships of bacteria than any system previously proposed (Fig. 22). The characteristic physiologic activities of the different groups are, for the most part, indicated in the generic names.

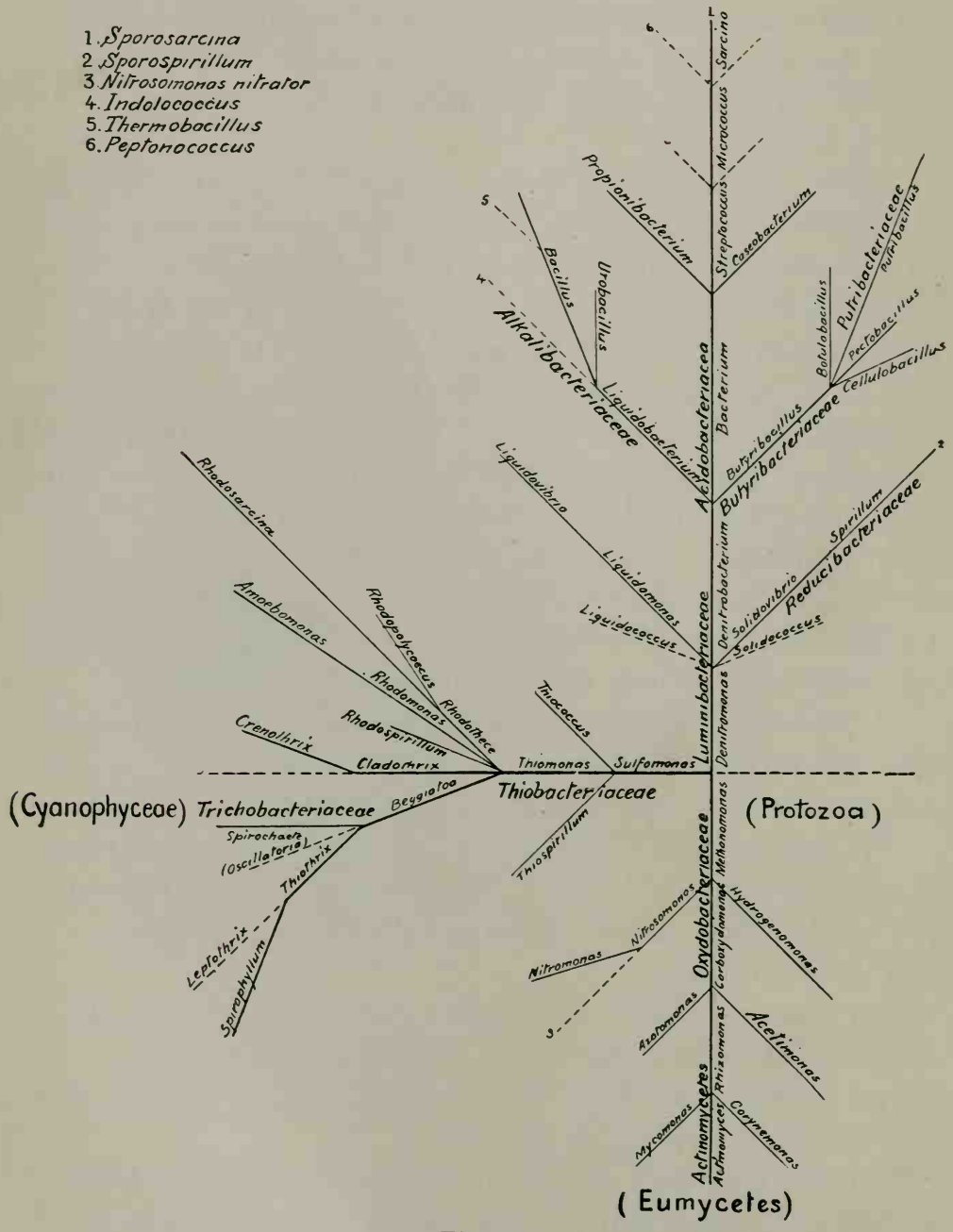


Fig. 22.

Undoubtedly, exception can be taken to details, such as the awkward character of the nomenclature and to other features of Jensen's classification, but in its insistence upon physiologic characters it marks a distinct advance.

One of the most frequently cited morphologic classifications of bacteria is that drawn up by Migula.* An outline of Migula's classification is given here for purposes of reference, and also because it illustrates the advantages and disadvantages that at present are inherent in any morphologic classification.

CLASSIFICATION OF BACTERIA.—(*Migula.*)

I. Cells globose in a free state, not elongating in any direction before division into 1, 2, or 3 planes.....1. Coccaceæ.

II. Cells cylindrical, longer or shorter, and only dividing in one plane, and elongating to about twice the normal length before the division.

a. Cells straight, rod-shaped, without sheath, non-motile, or motile by means of flagella. 2. Bacteriaceæ.

b. Cells crooked, without sheath.....3. Spirillaceæ.

c. Cells inclosed in a sheath.....4. Chlamydobacteriaceæ.

1. Coccaceæ.

Cells without organs of motion:

a. Division in one plane.....1. Streptococcus.

b. Division in two planes.....2. Micrococcus.

c. Division in three planes.....3. Sarcina.

Cells with organs of motion:

a. Division in two planes.....4. Planococcus.

b. Division in three planes.....5. Planosarcina.

2. Bacteriaceæ.

Cells without organs of motion.....1. Bacterium.

Cells with organs of motion (flagella):

a. Flagella distributed over the whole body...2. Bacillus.

b. Flagella polar.....3. Pseudomonas.

3. Spirillaceæ.

Cells rigid, not snake-like or flexuous:

a. Cells without organs of motion.....1. Spirosoma.

b. Cells with organs of motion (flagella):

1. Cells with 1, very rarely 2 to 3 polar flagella.....2. Microspira.

2. Cells with polar flagella-tufts.....3. Spirillum.

Cells flexuous.....4. Spirochæta.

4. Chlamydobacteriaceæ (Higher Bacteria).

Cell contents without granules of sulfur:

a. Cell threads unbranched.

I. Cell division always only in one plane.....1. Streptothrix.

II. Cell division in three planes previous to the formation of gonidia:

1. Cells surrounded by a very delicate, scarcely visible sheath (marine) .....2. Phragmidiothrix.

2. Sheath clearly visible (in fresh water) ..3. Crenothrix.

b. Cell threads branched.....4. Cladothrix.

Cell contents containing sulfur granules.....5. Thiothrix.

* Migula: "System der Bacterien," Jena, 1897.

The main subdivisions of bacteria into spherical forms (Coccaceæ), rod-forms (Bacteriaceæ), and spiral forms (Spirillaceæ), as set forth in this table, are such as are generally recognized by bacteriologists, but the establishment of genera upon the presence or absence of flagella is more open to objections. For example, in the group of rod bacteria organisms that are so fundamentally alike as B. subtilis (motile) and B. anthracis (non-motile)* would be placed in different genera if such a classification were logically carried out. This is actually done, for example, in Chester's classification of bacteria.† Again, the division of the spiral bacteria into two groups, according as the cells are rigid or flexuous, is not well founded. Careful investigation indicates that the typical spirochetes (*e. g.*, Sp. obermeieri) are rigid spirals.‡ In other words, such a classification is quite as arbitrary in the light of our present knowledge as a grouping based on physiologic distinctions.

Among the spherical bacteria, differences in the mode of grouping of the cells have given origin to certain names—as *streptococcus*, *staphylococcus* or *micrococcus*, and *sarcina*—that have been used as the names of genera, but no such generally useful distinctions have been found among the rod or the spiral bacteria. Consequently a term like bacillus has come to serve as the genus name for an enormous number of bacteria. Some of them are very different morphologically and physiologically.§ Recognizing the limitations of even the more satisfactory morphologic classifications, it has been a common custom for bacteriologists to class together for purposes of study those bacteria having in common certain well-defined and salient characteristics. Such a large and well-defined group of bacilli as the colon-typhoid group might be conveniently treated as an independent genus, and the same can be said of other groups of bacteria. The practice of dealing with bacteria in related groups is growing, and for the present it seems advisable to follow this tendency and not endeavor prematurely to establish a terminology based on morphologic features alone. The ordinary loose and

* See p. 215.

† Chester: "A Manual of Determinative Bacteriology," New York, 1901, pp. 190 and 276.

‡ Novy: Jour. Infect. Dis., 1906, 3, p. 315.

§ Bacillus subtilis, B. typhosus, B. tetani, B. prodigiosus, B. diphtheriæ.

confessedly unsatisfactory nomenclature is consequently adhered to in this book.

Nomenclature.—The present nomenclature of bacteriology may be criticized on two grounds: first, as already pointed out, for the unwieldy size that certain "genera" have been allowed to assume; and, second, for the haphazard way in which trinomial and even quadrinomial names have been bestowed. Such names can be properly employed only with reference to subspecies or varieties; and designations like B. coli communis, Granulobacillus saccharobutyricus mobilis non-liquefaciens, and Micrococcus acidi paralactici liquefaciens Halensi, are both cumbersome and unscientific. The use of a single genus name for a multitude of organisms is, in fact, responsible for the tendency toward trinomial nomenclature, and the remedy for both conditions would seem to lie in the abandonment of such a term as Bacillus for the name of a genus and the frank establishment of new genera on the basis of physiologic characters: such, for example, as distinguish the colon-typhoid group or the diphtheria group of bacilli. Until some such reform in nomenclature is brought about the names used to designate different kinds of bacteria will fail to make clear the group relationships which undoubtedly exist, and will continue to be a stumbling-block to all students of the subject.

Variations.—Like other living organisms, bacteria of the same species are not all precisely similar: races, strains, or individuals are found which differ more or less widely from the parent form. The term variation as used in biology signifies not the manifestation of certain apparently novel qualities that appear uniformly when organisms are placed under new conditions of life (latent characteristics or environmental modifications), but a constant difference in one or more features when the individual in question is compared under the same circumstances with one or more organisms of similar descent. Unlike the modifications due to environmental influence, variations are essentially dependent on elements intrinsic, not extrinsic, to the organism.* To illustrate: the ability of actinomyces (Ch. XXVII) to produce club forms is manifested only in the presence of animal fluids, but the production of the clubs is not

* This, however, is not to be taken to imply that the property of variation itself may not be affected by a change in environment.

an instance of true variation; a culture of actinomyces that did not produce clubs under these conditions would be properly regarded as a variant.

Two kinds of variability are commonly recognized: (1) Variations of the ordinary "fluctuating" type, which are distributed more or less systematically about a modal condition and may be grouped in a frequency curve or frequency polygon. As the term indicates, fluctuating variability swings to and fro, oscillating around an average type. The familiar deviations in human height exemplify this kind of variation. It is supposed by de Vries * that fluctuations remain fixed within certain limits, and that the accumulation of fluctuating variations can never give rise to a new quality in an organism or bring about the formation of a new species. (2) "Discontinuous variations," "sports," or "mutations," on the other hand, are supposed to be perfectly definite changes which arise suddenly without the interposition of a series of intermediate forms, and having once appeared, are permanent, and show no tendency to return to the mean of the parent form.

Among bacteria true mutations or sports are fully as rare as they appear to be in the higher forms of life. Very few well-accredited observations of the sudden appearance of mutants among bacteria are on record, and little attention seems to have been paid by bacteriologists to this subject. That discontinuous variations do occur, however, is shown by scattered observations made by Beijerinck † and a few others.

In general, bacteriologists will not hesitate to classify the variations with which they are most familiar as those of the fluctuating type. The number of them is practically infinite, and, especially in some groups, there is little doubt that they have been given too great classificatory value, as compared with precisely similar deviations in higher forms of life. At the same time these biologically trivial differences are often practically important, as in the study of pathogenicity or virulence.

A very characteristic and common form of variation among bacteria consists in the loss of some quality possessed by the organism when first taken under observation. The disappearance of the

* De Vries: "Mutationtheorie," 2 v., Leipzig, 1901–1903.

† Beijerinck: Kon. Akad. v. Wetenschappen, Amsterdam, Nov. 21, 1900.

power to liquefy gelatin, as in the Proteus group, or to produce pigment, as in the case of B. violaceus, and the loss of virulence, as in many pathogenic forms, are every-day occurrences in the bacteriologic laboratory. The term retrograde variety would seem appropriate for these forms if it had not already been applied by de Vries to mutations of a retrogressive character. In his terminology, both elementary species (the progressive forms) and retrograde varieties are supposed to have originated as sudden mutations. Now, so far as many of the more commonly observed retrogressions in bacteria are concerned, there can be no question that they arise from the accumulation of fluctuating variations, and not in any sudden and unexpected fashion. Minute divergences from the first culture grow more and more pronounced in each succeeding cultural transfer, and finally the once conspicuous and taxonomically important character may disappear altogether. Such retrogression, or, as it is often styled, degeneration, is no rare occurrence; it takes place with great uniformity, and follows definite and similar lines in a number of widely different organisms. In cultures, many totally unrelated organisms lose, by degrees, virulence, gelatinolytic power, or capacity for chromogenesis. Such a change goes on steadily and occurs in nearly all strains coming under observation. The varieties so formed grow luxuriantly and are perfectly stable under the conditions in which they are ordinarily kept; in fact, often they cannot be made to regain their lost property, even by successive transfers upon media considered to be especially favorable for the manifestation of the quality in question; they are spoken of as hopelessly degenerate. This is the case, for instance, with many strains of B. fluorescens as regards pigment production.

Qualities once lost, however, may under certain conditions be regained, as shown not only in the reacquisition of chromogenic power, but also in the reassumption of virulence by attenuated pathogenic races.

Connected with the variability of bacteria is their remarkable plasticity or adaptability to diverse conditions of life. By a series of inoculations or transfers it is possible so to alter bacteria that qualities originally present are sometimes accentuated, sometimes abolished. Bacteria may become adapted to very high temperature, to growth in the presence of antiseptics, and even to multiplication

in strongly bactericidal sera. Such modifications, as a rule, are gradually acquired and gradually lost. Pathogenic bacteria, like other parasites, may become so strictly adapted to life in the tissues of a given animal species that they neither grow readily in artificial culture-media nor in the bodies of animals closely related to the particular host. This seems, for example, to be the case with the leprosy bacillus, which, so far as known, is not able to grow anywhere except in the body of man and possibly the anthropoid apes. Theobald Smith* has made the important suggestion that bacteria of great pathogenic power should be looked upon as incompletely adapted parasites that have not yet succeeded in establishing an equilibrium between themselves and their host. The less complete the adaptation, the more virulent the disease produced. This would explain the tendency of long-established diseases to decrease in severity at the same time that they are becoming more frequent.

The question whether adaptation to a particular culture-medium, for example, or to a high or low temperature, is due to the selection of fluctuating variations or of mutations is one to which the existing evidence does not give a conclusive answer. On the whole, the available data indicate that change takes place by gradual progression rather than by sudden leaps. How far modification of individual cells and transmission of such modifications to the daughter cells is responsible for the observed conditions has not been determined.

* Smith, Theobald: Proceedings of Congress of Arts and Science, St. Louis, 1904, 5, pp. 219–239.

CHAPTER VII

BACTERIA AND DISEASE IN ANIMAL ORGANISMS

Theories of Disease.—In order to understand in some degree the influence of bacteriology upon medicine, it is worth while to recall the more important theories and conceptions regarding disease that have been held by the human race.

Probably one of the earliest notions of the cause of disease was a belief that an evil spirit or demon entered into or possessed the body of a man and there wrought various ills. This at least is the belief still widely prevailing at the present day among savage tribes, which represent in many particulars an early stage of culture, and one through which the ancestors of modern civilized man probably passed. "The possessed man, tossed and shaken in fever, pained and wrenched as though some live creature were tearing or twisting him within, ... rationally finds a personal spiritual cause for his sufferings. In hideous dreams he may even see the very ghost or nightmare fiend that plagues him. . . . . This is the savage theory of demoniacal possession, which has been for ages, and still remains, the dominant theory of disease and inspiration among the lower races. It is obviously based on an animistic interpretation, most genuine and rational in its proper place in man's intellectual history, of the actual symptoms of the cases."* This animistic or demonistic conception of disease still finds expression in the practices of the medicine-men or wizards of many savage peoples. Granting that a spirit is the cause of a disease, the logical proceeding is to induce the spirit to leave the body of the patient. Two modes of treatment are possible: the spirit may be lured out by propitiatory sacrifices, fair promises, or other conciliatory measures, or he may be forcibly evicted by powerful charms, by the beating of tom-toms, or by pummeling the body of the patient.

* Tylor: "Anthropology," New York, 1904.

Examples of the methods of treatment used by these two schools of medical practice may be readily found among the descriptions given by travelers of customs which prevail today among many primitive and half-civilized peoples. As regards one large class of diseased persons, the insane, the theory of demoniacal possession has remained current for obvious reasons up to comparatively recent times.

When the advance of natural knowledge brought a larger measure of understanding of the structure and functions of the human body than existed among the primitive peoples, a new and semi-scientific theory of disease sprang into being and attained world-wide influence. The Hippocratic theory of disease, as it was called, after its founder, Hippocrates, "the Father of Medicine," was, in fact, the dominant theory all through the middle ages, and still colors much medical thought and practice. According to this celebrated theory, the body contains four humors: blood, phlegm, yellow bile, and black bile. Health consists in a proper mixture of these four humors; disease, in an improper mixture. The doctrine of temperaments arose as an outgrowth of the Hippocratic theory: according as one or another humor preponderated a man was said to be of a sanguine, phlegmatic, or melancholic temperament. In acute disease the humors went through a regular process, being first of all *crude*, then passing through *coction*, or digestion, and finally being expelled by resolution or *crisis* through one of the natural channels of the body. The efforts of physicians were to be directed toward keeping the humors in their proper relations one to another, for if the normal delicate balance became disturbed, the most serious results might follow. This ingenious conception of disease held almost undisputed sway for a long period, and was hardly seriously questioned until the seventeenth century. In the seventeenth and eighteenth centuries a number of novel theories were propounded, but were of little aid to medical progress: in fact, many of the substitutes proposed for the Hippocratic theory were more complex and more mystical than the belief they were intended to supplant. Disease was "an intestine movement of particles," it was an attempt of nature to eliminate morbific matter, a want of "tone," a deficiency of stimulus, and so on. The theory of this class that lasted longest and had the greatest effect upon medical

practice was the so-called theory of homeopathy. The definition of disease given by Hahnemann, the founder of this school, is an index of the greater part of his teachings. "Disease," said this writer, "is a spiritual dynamic derangement of a spiritual vital principle." His theory of potentiality or dynamization maintained that medicines gained in strength by diluting, if the dilution was accompanied by shaking; the potency of some drugs was also supposed to be increased by pounding. Acting on this doctrine, Hahnemann ordered his original tinctures to be reduced in strength to one-fiftieth; these first dilutions again to one-fiftieth; and so on even to the thirtieth dilution, which he himself used by preference and to which he ascribed the highest "potentiality." An interesting outcome of this procedure was the fact that while such highly "potentialized" drugs could not be rationally supposed to have any physiologic effects, their administration to a patient was sometimes followed by more favorable results than was the more "regular" administration of drugs. A mode of treatment which consisted essentially in giving no medicine was sometimes as successful or more successful than the ordinary procedure. In a word, homeopathy, although theoretically ridiculous, did much to reform the custom of indiscriminate giving of drugs in large doses.

Amid the vagueness and confusion of such half mystical hypotheses as homeopathy, emerged the more tangible and definite germ theory of disease. As already pointed out, the germ theory of disease was the legitimate offspring of the germ theory of fermentation, and owed its origin to the memorable investigations of Louis Pasteur. The belief that the so-called infectious diseases are caused not by any enraged and revengeful spirit, not by any improper mixture of four humors, not by any spiritual dynamic derangement, but by small living plants and animals is now securely established. As regards such diseases as diphtheria, tuberculosis, and Asiatic cholera, this belief is no longer a hypothesis, but is based on indisputable fact. In respect to some other diseases, like yellow fever, hydrophobia, and scarlatina, while no specific micro-organism has been established as the cause, there can be little doubt that the germ theory of causation furnishes the most reasonable, consistent, and probable explanation of the nature of these infections.

Pathogenesis.—The conception of a pathogenic micro-organism

is a relative, not an absolute, one; that is to say, no microbe is known that is capable under all conditions of producing disease in all animals. As a rule, a pathogenic bacterium is limited in its activities to a small number of hosts; bacteria pathogenic for animals are not pathogenic for plants; very few of the bacteria that can infect mammals are also pathogenic for cold-blooded animals; some are even restricted to the tissues of a single species.

The power of a microbe to produce morbid effects or changes depends, therefore, primarily, upon the nature of the host. A bacterium that is pathogenic for one animal species may be harmless for another: the typhoid bacillus, when swallowed by man, can produce a serious, often mortal, illness; when fed to cattle, it produces no effect. As a consequence, no sharp line can be drawn between pathogenic and non-pathogenic micro-organisms. One of the common, typically saprophytic bacteria, the ubiquitous hay bacillus (B. subtilis), which is found almost universally in air, water, and soil, is capable of giving rise to a serious affection of the human eye.

The ability of a micro-organism to produce disease in individuals of a particular race or species may be modified by a number of general factors that predispose individuals to infection or endow them with resistance. The conditions that determine whether a microbe can bring about infection or not are very various. A few illustrations will suffice. The *age* of an individual is often of great importance. Experiments have shown that while the adults of certain animal species are resistant to inoculation with a particular germ, the young of the same species will succumb. The existence in the human race of a number of "children's diseases," which are not only more common, but more fatal, among children than among adults, is evidence to the same effect.* *Hunger* and *thirst* predispose to infection. If pigeons are kept on a low diet before, or just after, inoculation with anthrax bacilli, they die, although under normal conditions these birds are naturally immune to anthrax. Animals deprived of water also lose their natural resistance to

* In a series of nearly 70,000 cases of scarlet fever admitted to the Hospitals of the Metropolitan Asylum Board in London the case mortality per cent. was 18.2 among those under five years of age and 2.8 among those from twenty to twenty-five years.

anthrax inoculation. An unsuitable diet, as the substitution of bread and milk for meat, has the same effect. Excessive *fatigue* will predispose to infection. The normal white rat is highly insusceptible to anthrax, but when exhausted by work in a treadmill, becomes very susceptible. *Exposure to extremes of heat and cold* is well known to depress resistance to infection. This is shown by one of Pasteur's classic experiments, in which he rendered the naturally resistant hen susceptible to anthrax by chilling it with cold water. The prevalence of pneumonia in man in those months of the year when the influence of cold upon the human organism is most felt affords another illustration of the same fact. Frogs, which are immune to anthrax at ordinary room temperature, quickly die after anthrax inoculation if placed at a temperature of 25° to 35° C. Wasting diseases, like diabetes and typhoid fever, favor a secondary invasion of the tissues by micro-organisms, especially those belonging to the group of pyogenic bacteria. In diseases such as scarlet fever and smallpox the weakening of resistance due to the primary specific infectious agent is followed by the invasion of the tissues by streptococci, which are responsible for a large part of the injury done to the organism in these maladies.

In addition to these and other predisposing factors which affect the general resistance of the whole organism there are causes which influence the resistance of particular organs or groups of tissues. Local susceptibility may be increased by defective blood-supply, by rapid growth, by mechanical injury or trauma, and other factors. When streptococci are injected into the circulation of a perfectly healthy rabbit, they rarely settle on the valves of the heart, but if the aortic cusps of the heart have been injured prior to infection, the cocci gain a foothold there and set up an ulcerative endocarditis. The special liability of the bones and joints of young children to tuberculosis and suppurative affections is a well-known instance of local susceptibility. The organ or tissue that offers temporarily or constantly the point of least resistance is in each case the one to be attacked. The great danger of infection of the human mother at childbirth, unless every care be taken to prevent the access of bacteria to the uterine cavity, typifies the peculiar peril that arises when there is a concurrence of a severe local injury and a generally weakened condition.

Not only do the nature and state of the individual play an important part in determining the occurrence of infection, but the conditions influencing the infecting agent itself are also of great importance. The *virulence* of a micro-organism, that is, its power of growing in the body and producing injury, varies just as does the susceptibility of the host. Certain races or strains of bacteria occur that are characterized by a high or low degree of virulence, and there is no doubt that the varying severity of cases of infectious disease is due in part to differences in the virulence of the attacking germ as well as to differences in the resistance of individual hosts. Experimentally, for example, there is a great difference in pathogenicity for guinea-pigs between various strains of diphtheria bacilli isolated from diphtheritic throats. The virulence of a microbe for a particular species may usually be increased by successive animal inoculations, the microbe recovered from one animal being inoculated into another, and so on. The increased virulence acquired as a result of this method of animal passage does not necessarily obtain in the case of other host species. The virulence of streptococci for mice is increased by passage through the bodies of these animals, but at the same time the virulence for rabbits is diminished. Virulence may be decreased in a variety of ways, as, for example, by growth at high temperature or in the presence of antiseptics. A strain that has been weakened in virulence is said to be *attenuated.* An attenuated culture may be vigorous in other respects. Tubercle bacilli when first isolated from the mammalian body are usually quite virulent, but grow feebly on artificial culture-media; after some months' cultivation they grow more luxuriantly, but have lost in virulence.

The production of infection depends likewise upon the *number* of bacteria introduced into the body. An organism will often cope successfully with a small number of bacteria when the ingress of a larger number will cause a fatal disease. Ordinarily the injection into an animal like a rabbit of a few dozen or a few hundred bacteria has little effect, although it is said that inoculation with a single virulent anthrax bacillus will prove fatal to the very susceptible white mouse. In every case the number of bacteria necessary to produce infection will depend both upon the virulence of the

culture and upon the racial and individual susceptibility of the subject.

Routes of Infection.—The particular tissues with which a germ first comes in contact, that is, its path of entrance into the body, often exercises a decisive influence upon the production of infection. Injection directly into the circulation (intravenously) will many times bring about infection when subcutaneous injection of the same number and kind of germs fails to produce any effect. Some pathogenic bacteria may be taken into the alimentary tract with impunity, while a fatal infection will ensue if inoculation be made into the peritoneum; typhoid bacilli, for example, may be fed to an adult rabbit in large numbers without causing death or even serious illness, whereas intraperitoneal inoculation provokes a fatal infection. On the other hand, there is evidence that the spirillum of Asiatic cholera is much more pathogenic for man when swallowed than when introduced under the skin. Organs or tissues of weak vitality constitute a break in the line of resistance through which various bacteria may find their way: thus the human tonsils are a much-used portal of entry for pathogenic microbes. Vulnerability to a particular channel of infection may be incurred by mechanical injury or deranged metabolism: gastric disorders which alter the normal acidity of the stomach juices seem to predispose to infection with Asiatic cholera; inhalation of dust-particles in themselves not infectious is well known to increase the liability to pulmonary tuberculosis.

Bacteremia and Toxemia.—A distinction, in some respects important, is made between those infections in which bacteria become widely disseminated throughout the body and those in which they remain quite strictly localized. In the latter case general or constitutional symptoms may be produced through the action of soluble poisons which are absorbed at the point of their production and carried to distant organs. Diphtheria and tetanus are primarily toxemic diseases. In tetanus the bacilli are not found in the blood or internal organs; the local reaction caused by their presence is itself slight and often insignificant, and lesions have not been detected at the site of inoculation, but the toxin makes its way slowly along the nerves to the central nervous system, where it produces profound disturbance.

At the opposite pole from this condition are those general invasions of the organism in which bacteria multiply abundantly in the blood or tissues and are sometimes found on autopsy in large numbers in the capillaries in various organs. This condition of bacteremia is fairly common; in man bacteria are present in the blood not only in the so-called "blood-poisoning" maladies, but in diseases like pneumonia and typhoid fever. In some infections of lower animals, such as anthrax, the multiplication of bacteria in the body is the most prominent feature of the disease. It is possible, however, that micro-organisms multiplying in the body may produce poisons even though no poisons can be detected in artificial cultures outside of the body, and hence that in effect no strict dividing-line separates bacteremia from toxemia. Both multiplication and poison-production accompany infection as a rule, sometimes one factor being more prominent, sometimes the other.

The distribution of micro-organisms throughout the body varies greatly. In the toxemic diseases like diphtheria and tetanus the bacteria remain, as a rule, strictly localized. In others they are at first localized, but spread by continuous extension, as in erysipelas and many other infections. In still others they are borne in the lymph or blood-stream to a greater or less distance from the primary focus, and set up a secondary focus, or secondary foci, it may be in remote organs. This is the so-called spread by metastasis. Certain micro-organisms for unknown reasons settle in particular organs much more frequently than in others.

The term *pyemia*, or metastatic infection, is commonly applied to a condition in which secondary foci of suppuration appear, and multiple abscesses are formed in the internal organs and generally throughout the body. *Septicemia*, in the bacteriologic use of the term, refers to the presence or multiplication of micro-organisms within the blood; in this state the bacteria are found abundantly in the capillaries. It is here used in the same sense as *bacteremia*. The terms bacteremia and septicemia are applied by some writers solely to the presence of bacteria in the blood; as used by others they are limited to conditions showing multiplication of bacteria in the blood. There is no general agreement in respect to the latter restriction. The term septicemia is also used in surgery more

narrowly as applying to a condition in which the bacteria of suppuration invade the blood, but no abscesses are produced in the organs. Broadly speaking, pyemia is a particular variety or manifestation of bacteremia.

Mixed and Secondary Infections.—Physicians have long been aware that an individual might be attacked at one time by two or more infections. Diphtheria and scarlet fever, syphilis and gonorrhea, pneumonia (due to the pneumococcus) and typhoid fever, are combinations by no means unknown. It is possible that in some cases the different infections may originate nearly simultaneously, but such an occurrence is probably not common. Usually one infection precedes another, and the second is very frequently a more or less direct outcome of the first. Infection with certain micro-organisms predisposes to secondary infection with the pneumococcus; acute tuberculosis may develop during an attack of measles; streptococcus invasion of the lung tissues is common in pulmonary tuberculosis. Certain micro-organisms that can cause primary infection are also frequently found as secondary invaders. Pneumococci and streptococci are preëminent in this respect, and show a remarkable capacity for invading the body in the wake of other micro-organisms.

Mixed infections of a somewhat different sort are those in which the principal pathogenic organism is accompanied by auxiliary microbes, or, as some French bacteriologists have called them, accomplices, which by their presence influence the virulence of the chief infectious agent without themselves taking any very active part in the infectious process. The aërobic bacilli which usually enter a wound along with tetanus bacilli probably facilitate the growth of the latter and thus aid in producing infection. In other cases two or more pathogenic organisms may aid one another in weakening or breaking down the natural defenses. Diphtheria bacilli in the throat are often accompanied by streptococci, and there is reason to believe that such a mixed infection is more severe than an infection with diphtheria bacilli alone.

The External Defenses of the Organism.—*The Skin.*—As a rule, the unbroken skin presents an impassable barrier to micro-organisms. Virulent bacteria, especially staphylococci and streptococci, are found normally on the skin or between the superficial

horny cells, but are not able ordinarily to penetrate deep into the tissues unless favored by some cutaneous injury, such as a wound or burn. The ducts of the sweat-glands and the hair-follicles are, however, vulnerable points, and experiments have shown that it is possible for germs to make their way to the underlying tissues through these channels. Such an entrance through the uninjured skin must be regarded as exceptional. Even if the outer defenses are passed, the subcutaneous connective tissues present obstacles to further invasion, perhaps partly mechanically through rapid formation of new connective tissue, partly through the bactericidal properties of the lymph and the action of phagocytes.

The Mucous Membranes.—While the moist condition of mucous surfaces is favorable to bacterial multiplication, the constant removal of the layer of mucus tends to prevent bacteria from gaining permanent lodgment. The mucus itself has only a slight bactericidal power. The conjunctiva is protected both by irrigation with the mildly germicidal lacrimal secretion and by the action of the eyelashes and eyelids, although these mechanical defenses are frequently overcome by various pathogenic bacteria. The mucous membranes of the nasal cavities are protected to some extent against bacteria by the tortuous nature of the nasal passages, by the mechanical barriers interposed by the hairs, and also by the action of the ciliated epithelium, which sweeps mucus and dust particles outward. Nevertheless, streptococci and other organisms frequently use this path of entrance. The healthy human mouth presents a highly favorable environment for the development of bacteria, and it is not surprising that upward of fifty kinds of bacteria have been described as occurring in this locality. Pneumococci and streptococci are probably constantly present, and influenza and diphtheria bacilli are also often found in the mouth of persons apparently in perfect health, but who have been more or less intimately associated with patients or convalescents. The saliva is feebly germicidal, and when secreted in normal quantities, serves as a wash.

The Lungs.—The dust particles in a current of air cling to the moist surfaces with which they come in contact, and in this way air becomes largely freed from bacteria in the upper respiratory passages. Those bacteria that pass the larynx are caught in the

bronchi, and few reach the ultimate ramifications of the bronchioles. Both the fixed alveolar epithelial cells and the wandering leukocytes that enter the bronchioles and sacs have been observed to take up bacteria. Under some conditions, the nature of which is not clearly understood, the natural defenses of the lungs are broken down and infection of these organs appears to occur rather readily.

The Stomach.—The normal gastric juice is decidedly unfavorable to the growth of bacteria, a property due to the hydrochloric acid it contains, and this is doubtless the reason that the stomach is so free from infection. The action of the gastric juice does not, however, prevent the frequent ingress of swallowed pathogenic germs into the intestines, perhaps because such germs are frequently embedded in solid particles which protect them from the bactericidal action of the stomach fluid, perhaps because the gastric juice restrains development but does not kill. Tetanus and diphtheria toxins are rendered harmless by gastric juice, but a toxin sometimes found in tainted meat (produced by B. botulinus, p. 330) is not affected.

The Intestines.—The intestinal secretions have, on the whole, little restraining power over bacterial multiplication, although the bile has feeble germicidal properties. The peristaltic movements of the stomach and intestines also afford, it is thought, some degree of protection. The number of bacteria in the intestinal contents increases from the duodenum onward to the colon. Bacteria of more or less pathogenic power, such as streptococci and B. coli, occur in the healthy intestinal tract, often in large numbers. As long as the tissues are perfectly normal these organisms are quite harmless, but, like the pathogenic bacteria of the mouth and upper air-passages, their invasive power is increased by a diminution in the resistance of the tissues with which they are in contact. The intestinal disturbances in children under the influence of continued hot weather may be in large part due to the normal bacterial inhabitants of the intestines, rather than to any specific infection. On the other hand, well-known pathogenic bacteria like the typhoid bacillus and the cholera spirillum may exist in the human intestine, possibly multiply there to a limited degree, and be ejected in the feces without having induced disease.

The Transmission of Infection.—Some infectious diseases are

caused by microbes which are naturally saprophytic and which enter the animal body accidentally, as it were, rather than from choice of it as a culture-medium. Such, for example, seems to be the case with tetanus, the bacillus of which is not a parasite by conviction, but lives habitually as a saprophyte in soil and in the intestinal contents of the horse and some other animals. The other pathogenic anaërobes of the soil are also essentially saprophytic. As a rule, however, those bacteria that produce disease are more or less closely adapted to a parasitic existence, and pass from one animal body to another with only a relatively brief sojourn in the external world. The large majority of the bacteria causing infection in man are able, under ordinary conditions, to survive only for a very limited period apart from the human body. Hence the transmission of infection is in most cases dependent upon contact, either directly with an infected individual, or with material recently cast off from the body of such a person. Important differences exist in the resistance of pathogenic micro-organisms to the influences of external nature. The influenza bacillus and the gonococcus, for example, die off very quickly; the pneumococcus and the cholera spirillum are somewhat more resistant; while the tubercle bacillus and the typhoid bacillus are fairly hardy. Multiplication of pathogenic germs outside of the animal body, barring the soil anaërobes, occurs only in a few cases, and under rather exceptional circumstances, as possibly when diphtheria or typhoid bacilli find their way into milk.

From the point of view of preventive medicine it is especially important to note that pathogenic bacteria may exist for a long time in or upon the body of well individuals. After recovery from typhoid fever typhoid bacilli may continue to be discharged from the bowel or bladder for months or even years. Similarly, convalescents from diphtheria may harbor virulent diphtheria bacilli in their throats for long periods. It is also true that persons who have been in contact with infected individuals, although themselves remaining healthy, may be the carriers of disease germs. Influenza bacilli may be thus transmitted from a patient to another individual through the medium of a third person who is himself unaffected. There is reason to believe that the living carrier of dis-

ease germs as a principal or an intermediary is a highly potent factor in disseminating disease.

The path by which a disease germ leaves the body is influential in determining the route of infection. The typhoid germ frequently passes into sewers, makes its more or less devious way into a river, lake, or spring, and is perhaps eventually swallowed at a distant point. Diphtheria bacilli may be left by a child's lips on the edge of the school drinking-cup and so cause the infection of a playmate. Tubercle bacilli may be inhaled in the infectious droplets discharged by a consumptive in the act of sneezing or coughing. The infections of known origin, for the most part, are caused by germs thrown off from the mouth, from the intestines, from cutaneous sores, and in the genito-urinary secretions. In certain infections, not yet elucidated, such as the "acute exanthemata" (scarlet fever, measles, etc.), the infectious agent is perhaps contained in scaled-off epithelial cells as well as in discharges from the throat and nose.

CHAPTER VIII

IMMUNITY

Immunity, like pathogenicity, is a relative term; all living organisms, at least all the higher forms, are susceptible under some conditions to some kind of parasitic invasion.

On the other hand, some degree of resistance against parasitic attack seems to be manifested by all animals and plants. In certain cases the defense is so effective that bacteria and other parasitic micro-organisms rarely invade the body under natural conditions. The wild carnivora, for example, are probably practically exempt from bacterial infections. The cat and the dog, as is well known in bacteriologic laboratories, show, as a rule a, high degree of resistance to inoculation with bacteria that are highly pathogenic for other animals. In other cases infection occurs more readily. Man is susceptible to infection with a great variety of micro-organisms, certain of which possess little or no pathogenic power for any other animals.

Resistance to bacterial infection is often a natural inborn quality of a race or an individual. Such resistance is termed *natural immunity*, and is the converse of *natural susceptibility*. A state of natural susceptibility may be transformed by various causes into a condition of greater or less resistance, commonly designated as *acquired immunity*. Most civilized men are born naturally susceptible to smallpox, but acquire immunity during their individual lifetime by vaccination or by an attack of the disease.

There is reason to believe that the nature of the defense set up by the organism is not the same in all cases, and that natural immunity, in particular, is often due to an entirely different set of factors from acquired immunity.

Natural Immunity

Natural immunity sometimes depends upon the simple fact that a micro-organism which finds favorable conditions for multipli-

cation in one species of animal meets with unsuitable conditions in another species. Profound metabolic differences, such as those between warm-blooded and cold-blooded animals, are in themselves sufficient to account for much so-called natural immunity. In general, invertebrates are not attacked by parasites that invade the vertebrate body, and the lower vertebrates (frogs, fish, reptiles) are not affected by inoculation with the various bacteria pathogenic for birds and mammals. This is quite in keeping with the well-known physiologic and toxicologic differences between the various animal groups. Strychnin, which is so powerful a poison for vertebrate animals, has little effect upon protozoa, and quinin may be fatal to the malarial parasite at the same time that it exerts but a slight and temporary effect upon the human organism. The influence of body temperature upon infection is shown in the case of tetanus: many cold-blooded animals not normally susceptible to tetanus succumb to infection with the tetanus bacillus when they are kept in a warm chamber. Flesh-eating animals, as a rule, are less prone to infection than herbivora, perhaps because of the long-continued elimination of susceptible strains through the action of natural selection, more probably because of the difference in metabolism accompanying the difference in food.

Closely related *races* and species of animals sometimes display, one a natural immunity, another a natural susceptibility, to the same infecting agent. Field-mice are highly susceptible to glanders, house-mice almost completely immune. Jersey cows are more liable to tuberculosis than Holsteins, and Yorkshire swine are more resistant to swine erysipelas than some other porcine breeds. In man the immunity against particular diseases once thought to be possessed by certain races is not as marked as formerly supposed. No race of mankind seems to possess absolute immunity toward any human disease; in fact, such differences as are observed seem to be due very largely to differences in the opportunities for infection such as arise from diverse habits and pursuits.

Individual differences in the natural power of resistance in man come to light in the experience of every physician. Members of the same family exposed at the same time to the same possibility of infection show greatly varying susceptibilities. Variations

in degree of resistance to the suppurative infection of slight wounds and scratches are especially common and well known. It is impossible to eliminate in every case of natural infection the source of error due to differences in the amount and virulence of the infecting agent, but enough is known to indicate plainly the existence of individual susceptibility. In an epidemic of typhoid fever, due to an infected public water-supply, where it is fair to suppose that the specific microbe is distributed with some degree of uniformity through considerable bodies of water, it is well established that not all water-drinkers, even in the same household, contract the disease. Such differences in the degree of individual susceptibility can hardly be referred to any deep-seated metabolic unlikeness. There are, in fact, noteworthy fluctuations in predisposition in one and the same individual. The influence of apparently slight factors, such as a change in the weather or some degree of fatigue, is sufficient to turn the scale and transform a condition of resistance into one of susceptibility. In laboratory animals used for experimental work individual variations in resistance also occur, but are not so well marked as in man, and apparently oscillate within narrower limits.

The causes of natural individual immunity are unquestionably various, some of the factors involved being more or less under control, and therefore influenced by the observances of personal hygiene, while others are dependent on qualities so fundamental that they are hardly likely to be altered during the lifetime of the individual.

Instances of the close adaptation of particular parasites to particular hosts are common throughout the whole animal and plant kingdoms, and should not be confounded with the phenomena of natural individual immunity. A close mutual relation, for example, seems to subsist between the leprosy bacillus and the human organism, and it is as little enlightening to refer the non-infectibility of the dog or the rabbit with the leprosy bacillus to "immunity" as it would be to declare that Indian corn and the tobacco plant are "immune" to Tilletia tritici, the parasite of wheat smut. The relatively few instances among bacteria of abject dependence of a single species of parasite upon a single species of host is a fact doubtless connected with the wide range of bacterial conditions of life. It is

evident that the exemption of certain races or species of animals from the attacks of certain species of parasites is not necessarily referable to the same cause or set of causes that bring about the varying degrees of resistance evinced by individuals of the same species. The problems of natural individual immunity are closely connected in some ways with those of acquired immunity.

Acquired Immunity

Acquired immunity may be either active or passive.

Active immunity is due to the direct participation of the organism concerned, and depends upon increased cell-activity. Such immunity is gained at the expense and often at the risk of the organism acquiring it. Immunity to smallpox may be obtained either by an attack of the disease due to natural exposure, or by deliberate inoculation of dried material from pustules into the nostrils, according to a common practice in England in the eighteenth century, introduced from the Orient by Lady Mary Wortley Montague, or by the now common method of vaccination with cowpox virus. In each and every case this immunity depends upon a specific reaction on the part of the cells and tissues of the individual organism.

Passive immunity, on the other hand, involves no active generation of protective substances by the immunized animal. The latter is simply the recipient of substances formed in the body of another animal and transferred to the individual to be protected. In the preparation of diphtheria antitoxin the horse is actively immunized by the injection of increasing doses of diphtheria toxin, and the blood of the horse comes to contain a protective substance, the so-called diphtheria antitoxin. When a child has been exposed to diphtheria, it is the custom to inject about 1000 units of diphtheria antitoxin (p. 240) into the body of the child for protective purposes. The child is then measurably assured against an attack of diphtheria, and is said to have been immunized passively, since its own tissues have in no way shared in the manufacture of the protective substance. Passive immunity may be quickly acquired, but is also much less permanent than active immunity, and tends quickly to disappear.

Active immunity may be brought about in a number of ways:

(*a*) By the incorporation into the animal body of living, fully virulent bacteria;

(*b*) By the incorporation of living bacteria of diminished virulence;

(*c*) By the incorporation of dead bacteria;

(*d*) By the incorporation of bacterial products secreted or excreted during the life of the microbes;

(*e*) By the incorporation of bacterial products arising from the disintegration of the cells after death;

(*f*) By the incorporation of certain micro-organisms or their products which are not associated in any way with the production of the specific affection.

These may be briefly illustrated.

(*a*) Immunity produced by the introduction of living and virulent bacteria is practically identical with the immunity that results from an attack of disease after natural exposure. In experimental work the varying facility with which this mode of immunization can be effected is in part dependent upon the susceptibility of the organism to the particular parasite. A very susceptible animal can be immunized in this way only with great difficulty or not at all. Barber* has shown that a single anthrax bacillus, 3.5 μ long, can initiate a fatal infection in a white mouse. The successful use of living cultures involves the administration first of small non-fatal doses which are increased as rapidly as possible, as indicated by the intensity of the reaction. The relative insusceptibility to infection by some particular channel has been also taken advantage of, as in Ferran's method, now superseded, for protective vaccination of man against Asiatic cholera. In this disease natural infection occurs by way of the alimentary tract, and the subcutaneous injection of living virulent cholera spirilla is followed by a local reaction and some fever, but by no general infection or serious consequences. Up to the present this is the only instance in which virulent cultures have been used in the immunization of man, unless, indeed, the old practice of variolation advocated by Lady Montague is to be reckoned here. This is thought to be the principle of the empiric immunization of animals against cattle-plague† (Rinderpest).

* Barber: Jour. Infect. Dis., 1909, 6, p. 634.

† Gall taken from animals dying of cattle plague is used for immunization; the parasite concerned is unknown.

(*b*) Bacteria may be attenuated, that is, have their virulence diminished, in a variety of ways: (1) by growth at temperatures above the optimum, this being the usual manner of preparation of anthrax vaccines (p. 226); (2) by growth in the presence of weak antiseptics (*e. g.*, the anthrax bacillus in a medium containing carbolic acid 1:600); (3) by passage through the body of an animal of a different species, it being shown, for example, by Pasteur that the organism of swine plague, when passed through the bodies of rabbits, gained in virulence for rabbits but lost in virulence for swine. Pathogenic organisms may also be attenuated by growth on ordinary culture-media (pneumococcus), by continued cultivation in the presence of oxygen (bacillus of chicken cholera), by desiccation (virus of hydrophobia), and in other ways.

The injection of attenuated cultures may be sometimes followed, as in vaccination against anthrax, by injection of fully virulent cultures, more effective protection being secured in this way than by the use of attenuated cultures alone. The classic example of immunization by attenuated cultures is afforded by the ordinary procedure of vaccination against smallpox. Although the specific parasite has not yet been isolated, there is no doubt that the cowpox virus, the vaccine, contains an attenuated form of the smallpox parasite, weakened in virulence by passage through the body of the heifer.

(*c*) Immunization with dead bacteria has the merit of avoiding all danger of infection and at the same time of introducing into the body the substances most intimately connected with the bacterial cell and its activities. In experimental work upon animals the method has found wide application. Vaccination of man against three important diseases—Asiatic cholera, typhoid fever, and plague—has likewise been carried out with dead cultures. The particular methods used and results obtained are described elsewhere (pp. 289, 395). The use of dead bacterial cells for immunization has been most advantageous in such infections as those named above, in which no powerful soluble toxin is secreted by the cell in cultures, the toxic elements being seemingly bound firmly to the cell-substance. When a high degree of immunity is sought after, as in some kinds of experimental work, the injection of dead bacteria may be followed by that of living attenuated cultures, and finally by that of fully virulent ones.

(*d*) The preparation of diphtheria antitoxin furnishes the best studied instance of immunization by bacterial products. Briefly speaking, the method consists in injecting a horse subcutaneously with small quantities of broth in which a toxin-producing strain of B. diphtheriæ has been growing, gradually increasing the doses. The horse becomes immunized by this treatment, and is able, in a few weeks, to withstand many times the originally fatal dose. This immunity is due to, or at least usually accompanied by, the accumulation of the specific antibody, the diphtheria antitoxin, in the blood of the horse. It is evident that the broth in which the diphtheria bacillus has been cultivated, usually for about one week, must contain a variety of substances secreted or excreted by the living bacterial cell, but the substance to which the immunization is usually attributed is the specific diphtheria toxin.

Antibodies may be developed by feeding an animal with specific poisons as well as by injection. Ehrlich has immunized mice against ricin and abrin by feeding these animals with gradually increasing quantities of the poison until they have become able to resist several hundred times the lethal dose. Some degree of immunity has been achieved by feeding animals also with bacterial toxins or with dead cultures, but the results obtained in this way are less rapid and satisfactory than those reached by injection.

(*e*) The use of disintegrated products of the bacterial cell in immunization cannot be readily separated in practice from the two methods just considered. The use of dead bacteria must entail always the presence of some substances derived from the breaking up of the cells, and the use of broth in which bacteria have grown also involves the introduction of substances originating from dead as well as from living bacteria. At the same time some investigators (*e. g.*, Conradi) have advocated the employment of material obtained by the self-digestion of bacterial cultures (autolysis), and have considered that, owing to the speedier absorption of the physiologically active substances, more satisfactory results were secured by this method.

Successful results have also been reported by Macfadyen,* who, following the work of Buchner on the extraction of enzymes from yeast-cells by pressure, triturated washed agar cultures of

* Macfadyen: Centralbl. f. Bact., 1901, 30, p. 753; 1903, 34, pp. 616, 765.

the typhoid bacillus at the temperature of liquid air, —180° to —190° C. At this temperature the cells are brittle and disintegrate readily without admixture with sand or other triturating substances. The resulting cell-juices were found to be highly toxic and to possess strong immunizing properties.

(*f*) Some degree of immunity toward specific infections may be developed by the use of certain kinds of bacteria or bacterial products entirely foreign to the infection in question. In this category, for example, is the undoubted protection conferred against anthrax by the injection of B. prodigiosus or B. pyocyaneus or their products. Similar instances are the use of yeast in certain pyogenic affections, and, perhaps, the retarding effect of streptococcus infection upon certain kinds of tumors. The increased resistance of the organism so treated is sometimes ascribed to the "antagonism" of the bacteria or their products, but the phenomenon may be ascribed with greater plausibility to the increased leukocytosis resulting from the injection of proteid substances. (See p. 151.)

It is not always possible in practice to separate sharply the modes of immunization above outlined. The injection of an animal with a bacterial culture entails simultaneous injection with living bacterial cells, dead cells, secretion products, and products of disintegration, and it is evident that the results obtained may be due to the concurrent action of several factors. As already pointed out, however, the methods in ordinary use involve the predominance of one or another constituent.

A combination of passive and active immunization has been found advantageous in certain cases, a potent protective serum being used to pave the way for the introduction of living virulent cultures or powerful toxins. The injection of protective sera along with the more dangerous excitants of active immunity has been used with more or less success in swine erysipelas, cattle plague, foot-and-mouth disease, and anthrax.

The Mechanism of Immunity

(a) **The Antitoxins.**—It was first shown by Behring and Kitasato * in 1890 that the immunity of rabbits and mice which had been artificially immunized against tetanus was associated

* Behring and Kitasato: Deut. med. Wochenschr., 1890, 16, p. 1113.

with the ability of the cell-free blood to render harmless the toxic substances produced by the tetanus bacillus. The same investigators bestowed the name antitoxin upon that substance in the serum which thus nullified the toxin. The action of the antitoxin is manifested in the following direct way: If a fatal or many times fatal dose of toxin be mixed with an appropriate quantity of antitoxic serum in a flask, the injection of the mixture into a susceptible animal is not only not fatal, but wholly without injurious effect; the action of the toxin is wholly suspended because of its mixture with the serum taken from the immunized animal. This phenomenon does not depend upon the total destruction of the toxin by the antitoxin, as is shown by heating the mixture to a point sufficient to destroy the antitoxin, when it is found that the toxin remains after the heating and is able to exert its toxic power.* In other words, a more or less loose chemical combination of antitoxin and toxin takes place in the mixture, the poisonous properties of the toxin being held in abeyance as long as the union exists. The purely chemical nature of the relation of toxin and antitoxin has been clearly shown, especially by the work of Ehrlich. The rate of reaction between toxin and antitoxin, like other chemical reactions, is dependent upon temperature, concentration, character of medium in which the reaction occurs, and similar factors. The avidity of an antitoxin for its corresponding toxin differs in different cases; the union between tetanus toxin and antitoxin, for example, taking place less rapidly than that between diphtheria toxin and antitoxin. The precise proportion in which combinations occur involves some important questions, and is discussed elsewhere.

Little is clearly known about the chemical character of the antitoxins. In general, they are, like the toxins, unstable, complex bodies, readily destroyed by relatively low temperatures (65° C. to 75° C.), and losing strength steadily under exposure to light and air. They are very sensitive to the action of acids. They are best preserved for standards (Ehrlich) by evaporation of the sera to dryness in a vacuum at low temperature, and subsequent storage

* The method of destroying the antitoxin by heat is applicable only in certain cases, *e. g.*, pyocyaneus antitoxin; in many cases the antitoxin resists heat better than the toxin.

in vacuo in the dark at a low temperature and with protection from dampness. Attempts to obtain the antitoxin from milk or sera in purer or more concentrated form have been numerous. Treatment of immune sera with ammonium sulfate, magnesium sulfate, and other salts has shown that the antitoxins are precipitated with and are more closely bound to the globulins * than to the other protein bodies in sera, but whether the antitoxins are themselves to be ranked as proteins is uncertain. Several facts, such as non-digestibility with trypsin, seem to oppose their protein nature. Pröscher,† by the use of trypsin, has been able to obtain a diphtheria antitoxin that yields none of the ordinary protein reactions; Jacoby ‡ also has obtained an antiricin that responds to none of the protein tests.

Standardization of Antitoxins.—The strength of a given antitoxic serum, that is, its value as a neutralizing agent for the corresponding toxin, is a matter of considerable practical importance. It might be supposed that it would be a relatively simple procedure to determine the fatal dose of diphtheria toxin for a guinea-pig, for example, and then the amount of serum necessary to neutralize this, so arriving at the antitoxin content of the serum. Unfortunately, the conditions are more complex. Ehrlich found when different diphtheria toxins were used, or when the same toxin was tested at different periods, that a unit quantity of a given serum did not neutralize an equivalent number of fatal doses. The number of fatal doses that could be rendered harmless by equal amounts of the same antitoxic serum might vary within such wide limits as 30 to 130. In other words, the combining power of a given toxin for a given antitoxin is not an accurate measure of its toxic qualities. Since, however, the combining power itself remains constant within narrow limits, it is possible to establish an arbitrary standard unit upon which the relative strength of all antitoxic sera can be based. Such a standard antitoxin was first prepared by Ehrlich, and is preserved by him with all precaution against possible deterioration. A standard antitoxin serum based

* In some animals the antitoxins are found in the euglobulin fraction, in others in the pseudoglobulin.

† Pröscher: "Patentanmeldung," 1902, 6, p. 20.

‡ Jacoby: Hofmeister's Beiträge, 1902, 2, p. 535.

on Ehrlich's standard unit is also prepared in this country by the Hygienic Laboratory of the Public Health and Marine Hospital Service, and is distributed every two months to the licensed producers of commercial serum in the United States. By the use of this standard antitoxin it is possible to standardize a given toxin for use in testing the strength of antitoxin sera. Briefly, the procedure consists in determining by animal reaction two limits (Lat., *limes*): (1) the amount of diphtheria toxin necessary to neutralize exactly the standard unit: this is called the L_0 dose; (2) the amount of toxin which, when mixed with one unit of standard antitoxin, is just sufficient to kill in four days a guinea-pig of approximately 250 grams weight (this is designated as the L_+ dose). When these limits are established, it is then necessary to determine the smallest amount of the serum under test which, when mixed with the L_+ dose of toxin, will prevent the death of a guinea-pig of 250 grams weight for four full days. This amount of serum is considered to contain one unit of diphtheria antitoxin.*

Origin of the Antitoxins.—The appearance of a toxin-neutralizing substance in the blood of an animal injected with toxin raises a number of questions as to its source. The explanation naturally suggested itself to some investigators that the antitoxin was a "modified toxin" produced by transformation of the substance injected. It is found, however, that the quantity of antitoxin developed in an animal is often much greater than the equivalent of the toxin injected,† and, further, that the total antitoxin content of the body may continue to increase for some time after toxin injections have ceased. The difference between the permanence of active immunity and the evanescent character of passive immunity is also evidence against the modification theory, since, if the antitoxin arose by transformation, there would be no apparent reason why it should persist in the body longer in one case than

* Full details for making tests of the strength of a serum are given in the Report of the Committee on Antitoxin and Immunizing Sera of the American Public Health Association, Jour. Infect. Dis., 1905, Suppl. No. 1, p. 284, and in Bull. No. 21, Hyg. Lab. U. S. Pub. Health and Mar. Hos. Serv., Wash., 1905, pp. 1–92.

† According to Knorr (Münch. med. Wchnschr., 1898, 45, p. 321), in the horse one diphtheria toxin unit may produce 100,000 antitoxin units.

in the other. Such facts indicate that the antitoxin is probably generated in the tissues.

The active share of the animal body in the production of antitoxin being thus made highly probable, it remained to ask whether the antitoxin is a new substance hitherto unknown to the organism producing it, or whether it is present in small quantities in the normal organism and is simply increased in amount under the stimulation of toxin injection. Observation has shown that diphtheria antitoxin is found in about 30 per cent. of normal horses (Meade Bolton,* Cobbett †) and in about 50 per cent. of children, and 83 per cent. of adults, examined (Wassermann ‡). There is other evidence to the same effect, that before any toxic injection has been made or any attack of the specific disease has occurred antitoxin and other antibodies exist preformed in certain normal individuals. So far as has been discovered, the antitoxic substances present in the body of the normal organism are identical with those found in actively immunized animals (Wassermann §).

As already stated, antitoxins are found in the serum of immunized animals. They may also occur, though usually in much smaller amount, in the milk. There is no reason to suppose that the antitoxins are produced in the serum, although they are found there in considerable abundance. Every physiologic consideration points to the body-cells as the place of origin of the antitoxins. Kraus and Lipschütz ‖ have, in fact, shown that the extract of normal organs is richer in antitoxin against certain bacteriolysins than is the serum of the same animal. The precise tissues or groups of cells concerned in antitoxin production have not been certainly identified, and it is not likely that they are the same in all cases. From the foregoing statements it follows that when the antitoxins are once formed they do not reside in the body permanently, but are continually leaving it in the various excretions and secretions. This fact explains the difference in the permanence of active and passive immunity; in the latter, the antitoxin is excreted from the

* Bolton, Meade: Jour. Exper. Med., 1896, 1, p. 543.

† Cobbett: Lancet, 1899, 2, p. 332.

‡ Wassermann: Ztschr. f. Hyg., 1895, 19, p. 408.

§ Kolle and Wassermann: Handbuch, 4, p. 485.

‖ Kraus and Lipschütz: Ztsch. f. Hyg., 1904, 46, p. 49.

body like other foreign substances, whereas in active immunity the supply of antitoxin is maintained above the normal level through its continued manufacture by the body cells. It has been shown that when a measured quantity of tetanus antitoxin was injected into an animal, only one-third remained after six days and no trace could be found after twenty-one days. While the disappearance of antitoxin from the body is to be referred in part to the loss in excretions, there is evidence also that some of the antitoxin is destroyed within the body itself. This seems to be especially the case when heterologous serum (from a different species of animal) is used: the antitoxin introduced in serum obtained from an individual of the same species (homologous serum) remains longer in evidence. Thus the ordinary diphtheria antitoxin in horse serum when injected into the body of a child is eliminated more quickly than if injected into another horse. Varying results are obtained with different antitoxins and different species of animals, and the reasons for the disappearance of the antitoxin from the blood cannot be said to be understood in all cases.

Immunity and Antitoxin.—It is a pertinent question at this point how far the occurrence of antitoxin in the blood is competent to explain the resistance either of artificially immunized animals or of those naturally immune. The neutralization of toxin by antitoxin as demonstrated in test-tube experiments would lead to the supposition that a similar reaction takes place in the living body, and that when toxin is injected into the circulation of an immunized animal, it is rendered inert by the antitoxin in the blood in the same way as if mixed with antitoxin outside the body. In the main this is doubtless true, as shown especially by the facts of passive immunity, but there are certain phenomena that emphasize the difference between a test-tube and the living body. On grounds that will be set forth presently, there is reason to believe that the toxin has a chemical affinity for certain substances in the tissues as well as for the antitoxin in the blood. Any protective action of the antitoxin in the blood must, therefore, be due to its superior avidity for the toxin. Such superior avidity usually, but not always, exists. Some instances are known where the toxic substance unites with the tissue-substance in preference to combining

with the antitoxin in the blood.* The affinity of the cell-substance for the toxin is not a constant quality, but fluctuates under different conditions, notably in the upper limits of active immunization. The tissues of an animal treated with increasing doses of toxin sometimes become hypersensitive to the action of the toxin and, in spite of the fact that large quantities of antitoxin are circulating in the blood, the toxin combines by preference with the tissue-substance and causes the death of the animal. Tissue immunity is hence not always parallel with antitoxin immunity, and the presence of antitoxin in the circulating blood cannot be the whole explanation of the resistance shown by animals immunized against toxin, although it is the most evident and often the determining factor. Among the most important antitoxins that have been produced may be mentioned the diphtheria, tetanus, pyocyaneus, symptomatic anthrax, and botulism antitoxins, the antitoxins for various bacterial hemolysins, for snake, spider, and scorpion venoms, for the toxins in the blood or secretions of the eel, salamander, and toad, and for the vegetable toxins, ricin, abrin, robin and crotin. An antibody for a glucosid, the poisonous substance in poison-ivy, has recently been produced by Ford.†

The antitoxin found in the blood of some naturally immune animals may possibly be responsible in some degree for the resistance of such animals, but such an explanation is certainly not valid for all cases of natural immunity. The normal fowl exhibits almost complete immunity to the tetanus toxin, but contains no tetanus antitoxin in its blood, the toxin circulating unchanged for days after injection. The same is true of the alligator and some other cold-blooded animals (Metchnikoff). Immunity in these cases can be in no wise referable to antitoxic influence.

(b) **The Bactericidal Substances.**—Animal blood can not only neutralize bacterial toxins, but can destroy bacteria themselves. The systematic investigation of the germicidal power of normal blood began with the work of Nuttall ‡ in 1886. Nuttall showed, among other things, that the blood of one kind of animal does not

* Kraus and Lipschütz: Ztschr. f. Hyg., 1904, 46, p. 49.

† Ford: Jour. Infect. Dis., 1907, 4, p. 541.

‡ Nuttall: Ztschr. f. Hyg., 1888, 4, p. 353.

have the same germicidal strength for all species of bacteria, and that one and the same species of bacterium is affected differently by the blood of different animals. Two other important facts were early brought to light: (1) that the bactericidal power is lost when the blood is heated to 56° for one-half hour (Nuttall); (2) that the cell-free serum possesses the same power as the blood itself (Buchner).* The germicidal power of the blood *in vitro* is often considerable, a single drop of rabbit blood being able to destroy 53,700 anthrax bacteria (Lubarsch).†

The natural immunity of the normal organism was believed by Buchner and others to be due to the bactericidal activity of the blood, and the name *alexin* (Gr., to ward off) was suggested by Buchner for the substance that presumably exercised the protective influence.

It cannot be doubted that in certain cases the alexin content of the blood of an animal corresponds to the degree of immunity toward a particular infection. Thus the serum of the white rat, an animal that possesses a high natural resistance to anthrax, is very strongly germicidal for the anthrax bacillus. Especially significant is the increase in the germicidal power of the blood which is observed in animals artificially immunized.

The serum of guinea-pigs immunized against Spir. metchnikovii is strongly germicidal for this organism, while that of unimmunized guinea-pigs is devoid of specific bactericidal quality. In other cases, however, there is no relation between the resistance of an animal and the bactericidal power of its serum. An animal may be vaccinated against streptococcus infection, and indeed acquire a high degree of immunity toward streptococci, without coming to possess any specific germicidal quality in its blood. Normal human serum is strongly bactericidal for the typhoid bacillus, and yet this does not prevent the multiplication of this organism in the blood during an attack of the disease.

The relations between induced immunity and the appearance of bactericidal substances in the blood are best shown in certain experimental infections of animals, notably those caused by the

* Buchner: Arch. f. Hyg., 1891, 10, p. 84.

† Lubarsch: Centralbl. f. Bakt., 1889, 6, p. 481.

cholera spirillum and the typhoid bacillus. It is elsewhere pointed out (p. 393) that a specific choleraic poison or soluble toxin is not readily demonstrable in cultures of the cholera spirillum in ordinary culture-media. In correspondence with this it is found that animals immunized against the cholera spirillum contain no antitoxin in their blood. Immunity in such cases is associated with the antagonism of the body-fluids to the living cholera spirillum rather than with any toxin-neutralizing power, as shown by a series of convincing experiments by Pfeiffer, Wassermann, and others. A guinea-pig immunized against many times the fatal dose of living cholera vibrios is no more resistant than a normal guinea-pig to a fatal dose of dead vibrios. The resistance to infection with the living microbe is correlated with an increase in the specific bactericidal power of the serum of the protected animal. Thus, normal goat serum has only slight germicidal power for the cholera vibrio, 0.02 to 0.05 c.c. being needed to protect a guinea-pig against 2 mg. of a virulent culture, while 0.0001 c.c. of the serum of an immunized goat will protect against the same dose.

The fate of cholera spirilla introduced into the peritoneal cavity of an immunized animal was first followed microscopically by Pfeiffer, who gave a detailed description of the process (Pfeiffer's phenomenon).* The vibrios first lose their motility, then swell up and crumble into small fragments. These fragments finally melt away and disappear, the process being likened to the dissolving of wax candles in hot water. This lytic (Gr., to loose, dissolve) action of the immune serum is manifested not only within the peritoneal cavity of an immunized animal, but also when the peritoneal fluid or blood-serum is removed from the body and brought immediately in contact with the bacteria in a test-tube.

Many experiments have since been made with bactericidal serum *in vitro,* and the course of events is found to be essentially identical with that in the body. As in the case of the antitoxic sera, the antibacterial sera are specific: a serum that is highly lytic for the cholera vibrio may be without lytic effect on the typhoid bacillus. An important extension of our knowledge concerning sera has been effected by a study of the fate of red blood-corpuscles introduced

* Pfeiffer and Issaeff: Ztschr. f. Hyg., 1894, 17, p. 355.

into the animal body. The injection of the blood of a mammal or bird, for example, into the body of an animal of a different species is always followed by the appearance of a hemolyzing substance in the blood of the latter (Bordet *). This substance is specific, that is, it dissolves the hemoglobin out of the red corpuscles of the species from which the injected blood was derived and is without, or nearly without, action upon the corpuscles of other animals, although sometimes slightly affecting the blood of closely allied species. Thus the serum of a guinea-pig inoculated with rabbits' blood becomes hemolytic for the red corpuscles of the rabbit. Not only red blood-corpuscles, but other cells are capable of giving rise to antagonistic substances, or antibodies, when introduced into the animal body. A great variety of cell-dissolving (cytolytic) sera have been produced in this way. Injection of spermatozoa leads to the appearance, in the serum of the inoculated animal, of a spermatoxic substance that first renders the corresponding spermatozoa motionless and then kills them. It has been shown that such a serum resembles a hemolytic serum in all essential features. The claim has been made that such sera are histogenetically specific; that the cells of the kidney, for example, produce a "nephrotoxic" serum, those of the liver "hepatotoxic" serum, and so on, but specificity of this kind has not been demonstrated. It is more probable that a single type of cell can provoke the formation of several antibodies which affect cells of different morphology, but of somewhat similar chemical constitution.

The bacteriolytic and the hemolytic sera, therefore, fall under the same general head, and the common cytolytic phenomenon exhibited by the two kinds of sera are strikingly alike. A large part of our knowledge of the cytolytic sera and antibodies in general is due to the genius of Paul Ehrlich.†

The bactericidal sera possess the following important characteristics. When heated to 55° C. for one-half hour, the bactericidal power is lost; such sera are said to be inactivated. The addition of normal serum to heated serum, however, restores the original

* Bordet: Ann. de l'Inst. Past., 1898, 12, p. 688.

† Ehrlich, Paul: "Gesammelte Arbeiten zur Immunitätsforschung," Berlin, 1904.

potency. The relation between normal sera and immune sera may be exhibited in tabular form as follows:

	Germicidal Power
Normal serum	+
Immune serum	+++
Heated immune serum	—
Normal serum + heated immune serum	+++
Heated normal serum + heated immune serum	—

There is, therefore, no escape from the conclusion that the bactericidal property is due to the action of two substances, one that is present in the normal serum and in unheated immune serum, and a second substance of superior heat-resistance which is present in small quantities in normal serum and appears in much greater amount in the serum of immunized animals as a consequence of repeated inoculation with specific germs. The relation of these two substances will be considered elsewhere in connection with the receptor theory of Ehrlich.

An important factor in the production of antibacterial sera is the virulence of the culture employed. The use of highly virulent cultures conduces to the development of a particularly potent serum, and in experimental work it has been found desirable to use freshly isolated cultures of high virulence or cultures whose virulence has been exalted by animal passage. As a preliminary to the use of such hypervirulent cultures attenuated cultures may be employed.

The important question whether the bactericidal factor in normal serum (alexin) is identical with that in the blood of immunized animals is answered in the affirmative by most investigators, although there are a few dissenting voices. Both bacteriolytic normal and immune sera behave alike toward temperature and other influences, can be reactivated by unheated normal serum, and possess the same complex constitution. The lytic power of normal serum, like that of immune serum, is due to the combined activity of two substances.

Differences between Antitoxic and Antibacterial Sera.—The fundamental distinction between the antitoxic and the bacteriolytic sera has been set forth in the preceding pages. The antitoxic sera act directly upon the poison secreted by the living bacterial cell and neutralize its toxic property while the bacteriolytic sera affect the bacteria themselves and destroy them or paralyze their action. Since the antibacterial sera are without effect upon the

formed toxin, they are mainly useful in practice as a means of protecting against bacterial invasion, while the antitoxic sera (*e.g.*, diphtheria) may be employed to combat an infection already in progress. Broadly speaking, the latter are curative, the former protective. It must not be inferred that a given serum cannot be both antitoxic and bactericidal. If a horse be injected with a diphtheria culture containing both diphtheria bacilli and diphtheria toxin, the resulting serum will be not only antitoxic, but to some extent bacteriolytic.

The bacteriolytic sera have not yet been applied very successfully to the treatment of disease in man. This has been a stumbling-block to the advance of serum-therapy because most of the antisera hitherto produced are of this type. One reason for the failure of the bacteriolytic sera in human therapeutics may be that a serum of this sort produced in the body of one of the lower animals does not find suitable conditions for its specific action in the body of another species, such as man. There are facts which seem to support this view. The relative degree of success attained by vaccination with protective sera in several diseases is mentioned in connection with special topics. (See especially Asiatic Cholera, p. 395, and Typhoid Fever, p. 289.)

(c) **The Phagocytes.**—The brilliant researches of Metchnikoff * have definitely established the active share in combating bacterial invasion taken by certain white blood-corpuscles, denominated phagocytes, or "devouring cells." Metchnikoff's views have been sometimes referred to as the phagocyte "theory," but certain facts regarding the protection afforded by phagocytes are indubitably demonstrated.

A significant distinction exists between a local reaction and a general septicemic infection. The bacilli of chicken cholera injected subcutaneously into a rabbit produce no local inflammation, but multiply rapidly throughout the body, and the animal soon dies; the same bacilli injected into a guinea-pig provoke a strong local inflammation, the bacilli remain localized at the point of introduction, and spontaneous recovery takes place. In general, the degree of resistance shown by the organism is measured by the intensity of the local inflammatory reaction.

* Metchnikoff: "Immunity," Cambridge, 1905.

Perhaps the most characteristic feature of the local reaction or inflammation is the gathering of the leukocytes at the affected point, and this has been shown by Metchnikoff to rest on a broad biologic basis. In certain lower forms of animal life, such as the ameba, food-particles are engulfed bodily and digested within the cell. In multicellular animals, like sponges and jelly-fish, intracellular digestion by ameboid cells also plays an important rôle, and even in the higher metazoa both free-moving and sessile cells retain the power of devouring foreign particles. In the course of the metamorphosis of invertebrates, like the echinoderms and the insects, and of vertebrates, such as the frog, it has been shown that the superfluous tissues are picked apart by the leukocytes bit by bit and carried to another part of the organism. The absorption of larval organs by the activity of the phagocytes is closely connected with the behavior of the phagocytes toward foreign substances introduced into the body. Carmin granules, for example, are readily ingested by the leukocytes of warm-blooded animals as well as by the ameba. The resorption of the catgut used in surgical operations is a familiar instance of the digestion of foreign substances in the human body, and, like the disappearance of larval organs, is attributed to phagocytic activity. In specific cases of atrophy and absorption much discussion has arisen concerning the relative share of the phagocytes and the body-fluids in bringing about the changes observed, some investigators maintaining that the solvent action of the body-fluids is sufficient to account for the destruction of useless or alien material in the organism. While it may be sometimes difficult to assign to this latter factor its true value, there can be no question that Metchnikoff and others have conclusively established that the phagocytes can and do intervene in some of the typical processes of absorption and larval metamorphosis.

According to Metchnikoff, the phagocytes, besides acting as digesting cells and as scavengers, are also the chief defenders of the vertebrate organism against invading bacteria. "The diapedesis of the white corpuscles, their migration through the vessel wall into the cavities and tissues, is one of the principal means of defense possessed by an animal. As soon as the infective agents have penetrated into the body, a whole army of white corpuscles proceeds toward

the menaced spot, there entering into a struggle with the micro-organisms"* (Fig. 23).

Dog serum, for example, is without bactericidal power upon anthrax bacilli. If, however, anthrax bacilli are injected into a dog, they are quickly taken up by the leukocytes. The most plausible interpretation of these facts would seem to be that the natural immunity of the dog towards anthrax is due to the destruction of the bacilli by phagocytosis. In other instances where a normal animal is susceptible to infection with a particular microbe no phagocytosis is observed, but after the animal has been immunized by the injection of living or dead bacteria or their products, the phagocytes of the immune animal actively destroy the specific bacteria, no corresponding increase in the bactericidal power of the serum being observed. It has been shown, further, that while non-virulent pneumococci and streptococci are attacked and digested by leukocytes, virulent strains are not.

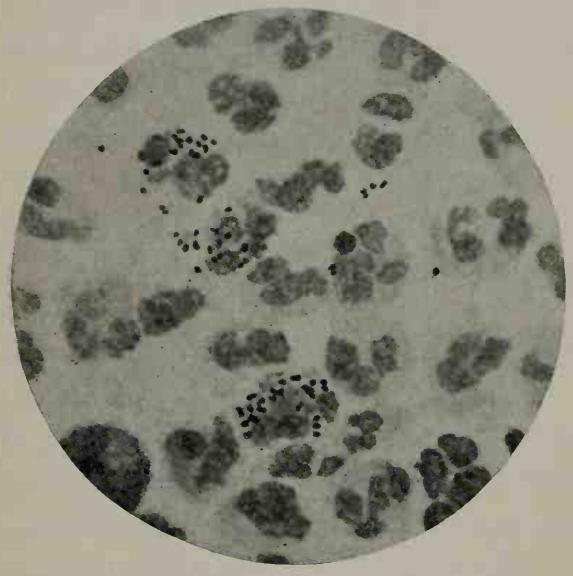


Fig. 23.—Phagocytosis of gonococci by leukocytes (Hicks).

Opsonins.—Phagocytosis may be intensified or diminished in various ways. Several observers have noticed that the power of leukocytes to destroy micro-organisms is greatly increased by the addition of serum from immunized animals, but only recently, chiefly through the investigations of Wright† in England, Hektoen‡ in the United States, Neufeld § in Germany, and their associates,

* Metchnikoff: "Immunity," Cambridge, 1905, p. 548.

† Wright: Proc. Roy. Soc., 1903, 72, p. 357; 1904, 73, p. 128, *et seq.*

‡ Hektoen: Jour. Amer. Med. Assoc., 1906, 46, p. 1407.

§ Neufeld: Deut. med. Wochenschr., 1904, 30, p. 1458; Ztschr. f. Hyg., 1905, 51, p. 283; Centralbl. f. Bakt., 1906, 36, p. 763.

has an explanation of this interesting phenomenon been obtained. These investigators have demonstrated that the activity of the phagocytes is conditioned by the presence in the blood and other fluids of certain substances which act in some unknown manner upon bacteria and prepare them for digestion by the phagocytes. These bacteriotropic substances have been termed *opsonins* (Lat., *opsono,* I cater for, prepare food for). Opsonins are present to some extent in the blood of normal animals, but they can be materially increased in amount by immunization.

It is a simple matter to demonstrate the existence of opsonins in a given serum by mixing the serum with bacteria suspended in physiologic salt solution. Leukocytes washed free from serum will take up some, but not a great many, of the bacteria. If, however, the bacteria are first treated with opsonic serum, they will be taken up in much larger numbers by the washed leukocytes. The opsonin enters into a more or less close union with the bacteria, as shown by the fact that opsonized bacteria can be washed in salt solution and still remain sensitive to phagocytosis. By these and other experiments it has been fully demonstrated that a substance is present in immune sera, and in a less degree in normal sera, which can so change or sensitize bacteria as to render them more liable to phagocytic destruction.

In determining the amount of opsonin present in a given serum the following technic is employed: A bacterial emulsion from a young (twenty-four-hour-old) agar culture is prepared in physiologic salt solution, great care being taken to insure that the emulsion is homogeneous. Equal volumes of leukocytes washed with salt solution, bacterial emulsion, and serum (diluted if necessary) are then mixed in capillary pipets and incubated for fifteen minutes at 37° C. Cover-slip films are then made from each pipet, and stained with some suitable blood-stain (as carbol-thionin or some one of the many modifications of the Romanowsky stain), and the average number of bacteria in each leukocyte is estimated by counts of the bacterial contents of 50 or more leukocytes in each film. The *opsonic index* is a mode of expressing the relative amount of opsonins in a serum when compared with the normal standard. It is obtained by dividing the average number of bacteria taken up by a leukocyte under the influence of a given serum by the average

number taken up by a leukocyte under the influence of standard normal serum and under otherwise perfectly comparable conditions. Thus:

	Average Number of Bacteria per Leukocyte (50 Counted)
Serum of tuberculous patient + washed leukocytes + suspension of tubercle bacilli	3
Serum of normal individual + washed leukocytes + suspension of tubercle bacilli	4
Salt solution + washed leukocytes + suspension of tubercle bacilli (control)	0.1

The opsonic index of the tuberculous patient in this illustration would be $3 \div 4$, or 0.75.

The technic of opsonic work seems peculiarly liable to lead to different results in the hands of different observers,* and there can be little doubt that much experience and great care are needed to obtain uniform and comparable results.

Certain facts regarding opsonins have, however, been practically established. Opsonins for many different bacteria are present in the sera of most, if not all, animals. Investigators are now agreed that after the injection of a suitable dose of dead bacteria there is usually a fall in the opsonic index of the injected animal, the so-called negative phase, and that this is followed by a rise above normal, and then by a more or less gradual return to normal. Natural infections in many cases are accompanied by a similar change in the opsonic index. It has been found in pneumonia, for instance, by independent observers that in the early stages of pneumonia the pneumococco-opsonic index is below normal, and that at about the stage of crisis the index rises considerably above the normal, returning again to normal in the uncomplicated cases leading to recovery. A similar course has been noticed in the streptococco-opsonic index in scarlet fever, the diphthero-opsonic index in diphtheria, etc.

Opsonins are largely destroyed by heating to 54° C. to 60° C. for thirty minutes; this seems to be due to the destruction of a substance which favors the opsonic action of a heat-resistant element; it is the latter which is specifically increased in immunization. In

* See, for example, Bull. Johns Hopkins Hospital, 1907, 18, pp. 232–255; Jour. Am. Med. Assoc., 1907, 49, p. 1249; R. E. Walker, Jour. Med. Res., 1908, 19, p. 237.

this respect and some others opsonins resemble other complex antibodies. They are, however, probably distinct from lytic amboceptors and agglutinins, as shown by the facts that a normal serum may be lytic but not opsonic, and, *vice versâ*, that immunization may give rise to one of these antibodies and not to others, and that the opsonic, agglutinating and lytic effects of serum are not destroyed in equal degree by heat. There is good reason to hold that opsonins are specific to the same extent as other antibodies.

The opsonic method of treatment has been extensively used during the last few years, especially by Wright and his associates. The aim of the method is to maintain the opsonic index, and consequently the phagocytic power of the blood, by the use of "properly adjusted and interspaced doses" at a high level. Frequent determinations of the opsonic index are considered by some to be necessary in this mode of treatment in order to guard against too great and too frequent production of the negative phase. Others would attach less importance to the opsonic content as an index to the administration of killed bacteria, and more importance to the clinical conditions and symptoms. The inoculation of dead bacteria and bacterial products has given distinctly encouraging results in the hands of Wright and others, particularly in the treatment of infection with pyogenic cocci, and of forms of tuberculosis localized elsewhere than in the lungs.

In view of all these facts, there can be no doubt that a local inflammatory reaction or a general increase in the number of leukocytes (leukocytosis) is a process of distinct advantage to the organism. The injection of certain substances which increase the general leukocytosis (collargol, nucleinic acid) has been practised by Mikulicz * and others with a considerable degree of success in attempts to enhance the resisting power of the body, prior to abdominal operations that involve grave danger of infection. The production of leukocytosis, however, is in itself of little value unless at the same time the amount of opsonin in the blood, the specific opsonic index, is high enough to favor phagocytosis. The simultaneous stimulation of leukocytosis and production of opsonins would, therefore, seem

* Mikulicz: Archiv f. klin. Chirurg., 1904, 73, p. 347.

to be the object to be aimed at in many of the bacterial infections that have so far proved most refractory to serum therapy.*

(d) **Ehrlich's Receptor Theory.**—The existence of toxin-neutralizing and bactericidal substances in the body-fluid of immunized animals has been already set forth. However these facts are interpreted, it must be remembered that the facts themselves are securely established. An ingenious and fruitful attempt to explain the mode of origin and manner of action of antitoxic and bactericidal sera has been made by Paul Ehrlich † in his widely known side-chain or receptor theory. Whatever be the ultimate fate of the speculations that have been built up around the central hypothesis, there can be no doubt that knowledge of immunity and the immunizing processes has been greatly increased by the stimulus given to research through the doctrine of receptors.

The receptor theory starts with the assumption that the various cells of the animal body, having to obtain their nutriment from the blood or lymph with which they are bathed, are endowed with the power of extracting from the ambient fluid those substances necessary to their life and well-being. This power of food appropriation is definitely localized in certain cell-substances, the so-called cell-receptors, which have combining affinities for food-substances. These food receptors have been conceived as standing in the same relation to the main body of the cell that the side-chains of certain complex chemical molecules of known composition hold to the central molecular nucleus. The receptors may be of simple constitution, adapted to the taking up of relatively simple substances, or they may be very complex and able to anchor large and complex proteid molecules of various kinds. Each cell may contain a large number of receptors of different affinities and degrees of complexity.

It is a plausible conception that when bacteria or other alien cells or their products are introduced into the body, the combining affinities of certain receptors may be satisfied by bacterial substances just as by the similarly constituted food molecules. The anchoring of

* An excellent résumé of the researches on opsonins is given by Hektoen in the Middleton-Goldsmith lecture, Jour. Amer. Med. Assoc., 1906, 46, p. 1407.

† Director of the Royal Prussian Institute for Experimental Therapy at Frankfort-on-the-Main. "Studies on Immunity," New York, 1906.

toxic substances, however, unlike that of food-substances, is followed by damage to the cell and loss of the particular side-chain or receptor that unites with the toxic element. When injury to the main body (Leistungskern) of the cell is not carried too far, repair can take place and the receptors be regenerated. According to a principle enunciated by Weigert, there is a tendency, in such cases of regeneration of lost parts, towards overcompensation, receptors being formed in excess of the needs of the cell and the surplus being discharged into the blood-stream. The *free receptors* are the *antibodies*, the antitoxins, agglutinins, antibacterial substances, antienzymes, and the like. The diphtheria antitoxin in the blood, then, is the same substance which, when in the cells, may be a peril to the cell by virtue of its affinity for the diphtheria toxin. If the toxin did not find in the body any substance with which it could combine,—for which, in other words, its haptophore group (p. 102) possessed an affinity,—it would be wholly inert and impotent as far as that organism were concerned. When, however, the free receptors are brought in contact with the toxin either inside or outside of the animal body, they unite with the haptophore group of the toxin molecule, thereby preventing the latter from entering into combination with the cell-receptors and perhaps damaging the cell irreparably.

There is evidence that the various bacterial toxins become bound in each case to particular cells of the organism. The tetanus toxin when mixed *in vitro* with emulsions of fresh organs manifests an affinity for different organs in different animals. In man, the horse, and the guinea-pig only the central nervous system is able to bind the tetanus toxin. This is altogether in accord with the clinical and histologic characteristics of tetanus. If a mixture of tetanus toxin and guinea-pig brain emulsion in suitable proportions is injected into a susceptible animal, the animal is entirely unaffected, just as if tetanus antitoxin (free receptors) had been used in place of fresh cell-substance (cell-receptors). The toxin is firmly bound in both cases and is quite unable to exert its toxic effect. That a real combination occurs between the toxin and the brain-substance is further shown by mixing tetanus toxin and normal guinea-pig brain emulsion and allowing them to remain in contact for a certain period; on centrifugalizing the mixture the supernatant fluid is found to be

entirely toxin-free. In some other animals, for example, the rabbit, other organs besides the central nervous system are capable of binding the tetanus toxin.

Metchnikoff has shown that the alligator injected with tetanus toxin does not sicken, and that this is because of the lack of sensitiveness of its central nerve-cells to the toxophore group; experiments *in vitro* prove that certain organs of the alligator are able to bind the tetanus toxin, and, furthermore, in accord with this, tetanus antitoxin is produced by injection of tetanus toxin into the living alligator. It follows that antitoxin production does not necessarily depend upon the susceptibility of a given animal to a given toxin. It is sufficient that the animal possesses receptors able to bind the haptophore group of the toxin. So far as antitoxin formation is concerned, it would seem to be a matter of indifference whether or not the toxophore portion of the toxin molecule is present to injure the cell.

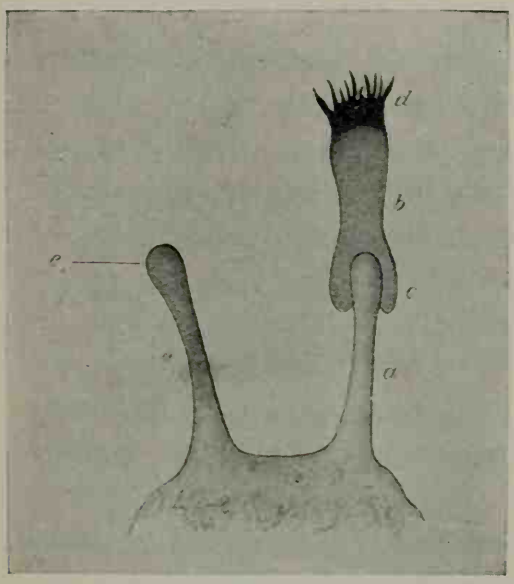


Fig. 24.—Graphic representation of receptors of the first order and of toxin uniting with the cell-receptor: *a*, Cell-receptor; *b*, toxin molecule; *c*, haptophore of toxin molecule; *d*, toxophore of toxin molecule; *e*, haptophore of the cell-receptor (Ehrlich).

The constitution of bactericidal sera is more complex than that of antitoxic sera, as already pointed out, and the mode of action of the former is correspondingly less simple. Ehrlich has postulated the existence in the living cell of three kinds of receptors, designated respectively as of the first, second, and third order (Figs. 24, 25, 26).

In the case of the bactericidal sera, therefore, the specific antibody (receptor of the third order) possesses two affinities, one for the specific bacterial cell, one for the labile, activating substance present in normal serum. The peculiar function of the antibody lies in bringing together in close relation this ingredient of normal serum and the bacterial cell; hence it has been called the intermediary

body (Zwischenkörper), but in more recent nomenclature it is known, in agreement with Ehrlich's conception of its nature, as the *amboceptor*. The constituent of normal serum is designated by Ehrlich and his followers as the *complement*. Every amboceptor is consequently possessed of two different combining groups, the complementophile, having an affinity for the complement, and the cytophile, having an affinity for some specific cell. A number of different amboceptors may coexist in the body of the same animal; the blood of one animal may be bactericidal for a variety of different microbes, and the specific amboceptor for one kind may be removed by appropriate methods without affecting those of other affinities. There is also experimental evidence for believing in a plurality of complements, and perhaps one reason why the bactericidal sera have not been very successfully applied in human therapeutics is because there is a lack of complements in human serum adapted to amboceptors produced in the bodies of the lower animals.

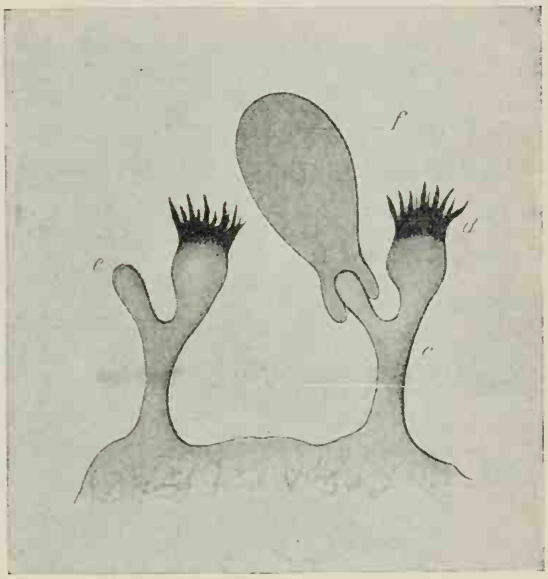


Fig. 25.—Graphic representation of receptors of the second order and of some substance uniting with one of them: *c*, Cell-receptor of the second order; *d*, toxophore or zymophorous group of the receptor; *e*, haptophore of the receptor; *f*, food-substance or product of bacterial disintegration uniting with the haptophore of the cell-receptor (Ehrlich).

The complement being assumed to be the active agent in the various cytolytic sera, the question arises as to the nature of this substance, and here it must be admitted that little or nothing is known beyond the bare physical characteristics already stated. At one time the complements were supposed to be of an enzyme nature, but there is little to support this view. Kyes * has made the im-

* Kyes: Berl. klin. Wochenschr., 1902, 39, pp. 886–918.

portant discovery in work on snake venom that a definite chemical substance, lecithin, can act as a complement.

Along the line of Ehrlich's receptor theory, Welch * has introduced the conception of the throwing-off of antibodies by pathogenic micro-organisms within the body of their host. Just as the cells of the host generate substances antagonistic to the cells of invading parasites and their products, so it is supposed that the parasites, by a similar mechanism, may produce amboceptors with affinities for certain tissue-cells. Linked with a suitable complement,

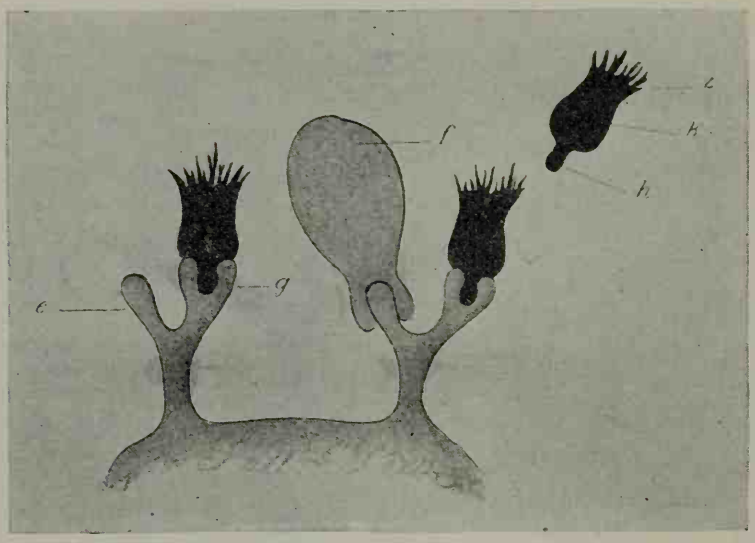


Fig. 26.—Graphic representation of receptors of the third order, and of some substance uniting with one of them: *c*, Cell-receptor of the third order, amboceptor; *e*, one of the haptophores of the amboceptor with which some food substance or product of bacterial disintegration, *f*, may unite; *g*, the other haptophore of the amboceptor with which complement may unite; *k*, complement; *h*, the haptophore, and *z*, the zymotoxic group of the complement (Ehrlich).

such amboceptors may exert a poisonous action upon the cells of the host.

A singular phenomenon, studied especially by Neisser and Wechsberg,† is the reaction obtained when varying amounts of immune serum are added to constant volumes of normal serum and bacterial emulsion. When very small amounts of immune serum (amboceptor) are added, no bacteriolysis takes place; on increasing the amount of immune serum complete bacteriolysis finally occurs;

* Welch: Johns Hopkins Hosp. Bull., 1902, 13, p. 285.

† Neisser and Wechsberg: Münch. med. Wchnschr., 1901, 48, p. 697.

but on adding still greater quantities of immune serum, bacteriolysis once more fails to appear. From these and similar experiments it was concluded that a "*deviation of complement*" occurs under conditions where the amboceptors are in great excess, that is to say, some of the amboceptors combine with the complement, but others are left free, and these free amboceptors unite with the receptors of the bacterial cells more rapidly than the complement-amboceptor group, thus blocking the way for the latter combination and leaving it unable to act.

The expression "*fixation of complement*" has been used for a somewhat similar phenomenon. When the serum from a typhoid patient is mixed with an extract of typhoid bacilli, and complement is added, the mixture, after a short period of incubation, will not reactivate a heated hemolytic serum. This is interpreted as meaning that the complement in the mixture has been bound. The method affords a very delicate test of the presence of specific antibodies or antigens in the serum of a patient. By this means antigens have been shown to exist in the organs of syphilitic subjects, and the method has been used likewise in certain special cases for the diagnosis of gonococcus, meningococcus and other infections. For a full description of the procedure see an article by Meakins.*

Other Reactions Produced by Bacteria

When bacterial cells and their products are injected into an animal, the cells of the animal react in such a way as to give rise to a variety of substances besides the antitoxins and bacteriolysins (amboceptors) already considered. Among the better known and most important of these are the agglutinins.

(a) **The Agglutinins.**—If the blood or blood-serum of an animal previously inoculated with the typhoid bacillus is added to a suspension of typhoid bacilli, the latter soon become motionless, and after a while the individual bacilli become aggregated in irregular masses. The same process of clumping usually occurs if, instead of the blood of an injected animal, the blood of a typhoid fever patient be employed. The reaction is specific, although not absolutely so. That is, the serum of either a typhoid patient or an

* Meakins: Johns Hopkins Hosp. Bull., 1907, 18, p. 255.

animal injected with typhoid bacilli will agglutinate typhoid bacilli in high dilutions, while other bacilli, as a rule, are unaffected, although it is true that those more closely related to the typhoid bacillus, such as B. coli and B. paratyphosus, may be slightly clumped, especially by the lower dilutions. Many other bacteria as well as those of the colon-typhoid group are agglutinated in a similar manner by their respective antisera.

The agglutination of bacteria by blood-serum has been utilized in two ways: first, in the diagnosis of certain specific diseases like typhoid fever, where the serum from the suspected case is added in appropriate dilutions to a suspension of typhoid bacilli; and, second, in identifying bacteria, for which purpose a serum of known agglutinating properties is mixed with a suspension of the germ whose character is to be determined. The former, the Gruber-Widal test, has come to be extensively used in the diagnosis of typhoid fever, and when carefully controlled, is a valuable aid in diagnosis; the identification of bacteria by the agglutinative reaction is, on the other hand, less satisfactory, and there are many objections to its unqualified acceptance.

Technic.—The technic of the agglutination test calls for the observance of manifold precautions. An agar culture eighteen to twenty-four hours old is preferably employed. From this a faintly turbid suspension in sterile physiologic salt solution is prepared. The suspension of the bacteria must be homogeneous; for some cultures a thorough shaking will suffice, for others recourse must be had to passage through filter-paper. In any case a uniform method of preparation must be employed in every series of experiments, and care taken to obtain as nearly as possible the same number of bacteria in a given volume of the suspension. The nature and reaction of the medium on which the bacteria are grown, the age of the strain and its origin, and other factors influence the course of agglutination. Some strains are naturally more readily agglutinable than others; some may be inagglutinable even by a potent serum.

The serum for the test may be obtained from a blister made by the application of a cantharides plaster, or from blood drawn from the ear-lobe or finger-tip and centrifugalized or allowed to clot in a sterile tube. The substance in the serum that causes the agglutination of the bacteria is known as *agglutinin*. It is fairly

permanent and may persist in dried blood or serum for a long time in unchanged strength. In public health work a few drops of blood may be dried on a strip of aluminum foil, which is then mailed to a central laboratory, where flakes of the dried blood are weighed and dissolved in appropriate amounts of salt solution so that the test is made as accurately as with fresh blood.*

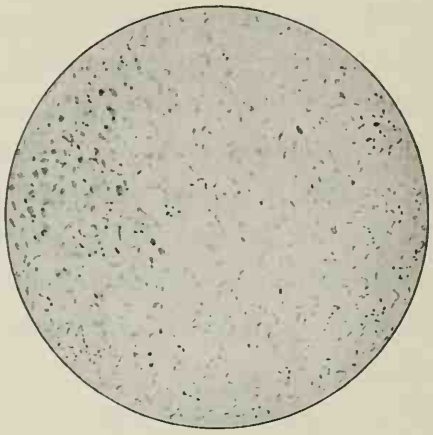


Fig. 27.—Typhoid bacilli, unagglutinated.

Appropriate dilutions of the serum or blood with physiologic salt solution are mixed with measured quantities of the bacterial suspension, and the process of agglutination followed either with the naked eye or with the microscope. The microscopic examination, made with high powers, shows a gradual cessation of motility in such organisms as the typhoid bacillus, accompanied by the sticking together first of a few cells, then of larger numbers, until in typical and decisive reactions large masses of agglutinated cells are found which are plainly visible with a low power. The maximum clumping is generally reached in about six to eight hours (Figs. 27, 28, 29). Sometimes "spontaneous agglutination" occurs, so that a suspension to which no serum has been added should always be observed along with the others, in order to avoid this source of error.

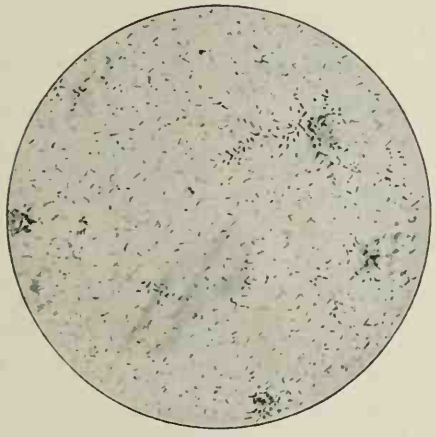


Fig. 28.—Typhoid bacilli partially agglutinated.

The naked-eye test gives, as a rule, more trustworthy results than the microscopic. Varying dilutions of serum are mixed with a definite quantity of bacterial suspension in small thin-walled glass tubes, and placed in the incubator. The tube containing only the

* See Wesbrook: Jour. Infect. Dis., Suppl. No. 1, 1905, p. 315.

bacterial suspension remains cloudy, while those tubes to which agglutinating serum is added show a general clearing-up of the fluid, ranging from the appearance of a flaky deposit on the walls of the tube, with high dilutions of serum, to a complete sedimentation of the bacteria and clear supernatant fluid.

Temperatures above 60° C. diminish the agglutinability of bacteria; agglutinin also is weakened by heating to 60° to 70°, and is destroyed at 75°. Serum dried and protected from light retains its power indefinitely.

Properties and Mode of Action of Agglutinins.—Agglutination is brought about by the chemical interaction of two substances, one a constituent of the agglutinating serum, the *agglutinin*, the other a bacterial substance, the *agglutinogen*. The latter substance receives its name from the fact that when introduced into the animal body it stimulates the formation of agglutinin. In terms of Ehrlich's receptor theory the agglutinogen contains a haptophore or combining group, which enables it to unite with certain receptors of the tissue cells. These are "receptors of the second order" (Fig. 25), and contain a haptophore group which binds them to the agglutinogens, and a zymophore group of enzyme-like activity which brings about the change in bacterial cells that leads to their agglutination. The agglutinins, then, appearing in the serum of immunized animals, are cast-off cell receptors which have been produced over-abundantly as a consequence of the union of the bacterial agglutinogen with normal cell-receptors. It has been supposed that the zymophore group of the agglutinin may degenerate or be destroyed by heat or chemicals, leaving the haptophore group virtually unaltered, and to such hypothetical bodies the name of *agglutinoids* has been given, from their assumed analogy to toxoids (p. 97). It is further supposed that agglutinoids, by virtue of the haptophore group that they possess, may combine with the agglutinogen of the bac-

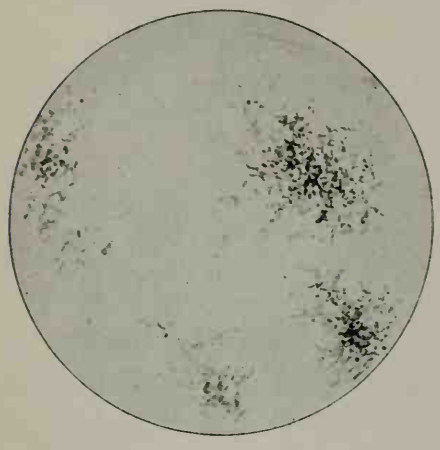


Fig. 29.—Typhoid bacilli, showing typical clumping by typhoid serum.

terial cell, thus blocking the way to reaction with intact agglutinins and interfering, it is believed, with the agglutination reaction. Recent investigators, however, express doubt as to the existence of definite agglutinoids.*

It is essential that some mineral salt be present in order that agglutination shall occur. Following out this clue, considerable light has been shed on the real nature of the agglutinating process. It is found that the same laws that govern the precipitation of colloids in suspension and finely divided particles, like kaolin, also hold for the agglutination of bacteria. The ability of a salt to agglutinate bacteria and to precipitate colloids depends on the degree of dissociation and on the valency, speed of migration, and decomposition tension of the kation. In a word, agglutinin is supposed to reduce the amount of negative electricity with which bacteria are charged and so render the bacteria more susceptible to the precipitating action of the salts.

Not bacteria only, but other free cells, are clumped by both normal and immune sera. The red blood-cells of any species of animal are agglutinated by the serum of an animal which has been previously injected with cells of similar origin. The "hemagglutinins," so far as they have been studied, resemble the bacterial agglutinins in all essential features. Some bacterial cultures have been found to contain hemagglutinins, and it is possible that the thrombi observed in the blood-vessels after death from certain infectious diseases may be due to hemagglutinins of bacterial origin.

Substances that agglutinate bacteria and erythrocytes are found in the blood of many normal animals. The serum of a young uninoculated horse, for example, has been observed to agglutinate paradysentery bacilli in a dilution of 1:1000 (Park).† The relation between normal and immune agglutinins is not known.

Group Agglutination.—The serum of an animal inoculated with a given micro-organism agglutinates not only the particular species used for inoculation, but very often also other organisms biologically related to the infecting agent. As a rule, agglutination of the organism used for inoculation, the so-called "homologous" organ-

* Buxton and Vaughan: Jour. Med. Res., 1904, 12, p. 115. Buxton and Torrey: Ibid., 1906, 15, p. 3.

† Park: Jour. Infect. Dis., Suppl. No. 2, 1906, p. 1.

ism, is the most marked, that is, it will occur with higher dilutions of serum than is the case with other organisms of the same group. Thus the serum of a rabbit inoculated with typhoid bacilli shows a higher agglutinating power for the typhoid bacillus than for other members of the colon-typhoid group, although the agglutinating value of the serum for B. enteritidis, B. coli, or other members of the group may be distinctly greater than that of normal serum. Sometimes, however, the accumulation of "group agglutinins" and "specific agglutinins" seems to follow a very irregular course. This is especially true in the serum of an animal like the horse, which contains a high proportion of normal agglutinins, so that group agglutinins may be even more abundant than specific agglutinins after repeated injections. Park has observed one instance where the serum of a horse after eighteen injections with the "Manila" strain of the paradysentery bacillus agglutinated a colon bacillus more strongly than it did the homologous organism.

Experiments show that saturation of a specific agglutinating serum with the homologous bacterium removes not only the specific agglutinin, but some, or it may be all, of the group agglutinins. In fact, bacteria may absorb group agglutinins that they themselves have not produced and that do not visibly affect them. The use of the absorption method for determining the existence of mixed infection may therefore lead to wrong conclusions unless high enough dilutions of the serum are used to eliminate the action of the group agglutinins.

The complexity of the phenomenon of agglutination of bacterial cells is well illustrated by the observation of Smith and Reagh * that the flagella of motile bacteria may contain one kind of agglutinogen which gives rise to a corresponding agglutinin, while the cell-body of the same organism contains another kind, giving rise to a different agglutinin.

In the light of all these facts it is evident that the specificity of agglutinating sera is not absolute, and that such sera can be safely used to identify bacteria or to diagnose disease only when due care is taken to avoid all the manifold sources of error and misinterpretation.

* Smith and Reagh: Jour. Med. Res., 1904, 10, p. 89.

The Relation Between Agglutinating and Bactericidal Power.—Although some observers have maintained that there is a direct relation between the agglutinating and bactericidal properties of a serum, the following facts show that the bacteriolysins and agglutinins are entirely distinct: (*a*) The bactericidal power of a serum is destroyed at 56°, while the agglutinins resist a temperature of 62° or higher. (*b*) In the serum of an animal injected on successive dates with a bacterial culture the respective increase in the bactericidal and agglutinating power do not run a parallel course or indeed show any connection. (*c*) The agglutinin may be absorbed from a serum, leaving the bactericidal power of the serum unimpaired.

(*b*) **The Precipitins.**—When the germ-free filtrates from broth cultures of bacteria are mixed with the respective antisera produced by animal inoculation, the formation of a powdery precipitate occurs.* The precipitation thus produced is approximately specific in its nature, the filtrate from a typhoid culture giving a precipitate with typhoid immune serum, but not, for example, with cholera immune serum. The substance in the immune serum that provokes precipitation has been termed *precipitin.*

Bacterial precipitins are by no means the only kind that may be produced by this method. A great variety of albuminous bodies when injected into animals give rise to corresponding antibodies which possess the power of causing precipitation of the substance used for inoculation. Injection with milk brings about the formation of a precipitin which throws down the casein of the milk used for injection, but does not act on the casein of the milk of other animals. Egg-albumin likewise gives rise to precipitins that are specific.

A particularly important development of the study of the precipitins has been the utilization of the specific character of the reaction for the purpose of medicolegal investigation.† The serum of an animal which has been injected with human blood produces a precipitate when mixed with human blood even in high dilutions, but has no such effect upon the blood of the lower animals. A simple, delicate, and highly trustworthy method for distinguishing human blood-stains is thus afforded, and the value of the precipi-

* Kraus: Wiener klin. Wchnsch., 1897, 10, p. 736.

† Uhlenhuth: Deut. med. Wchnsch., 1901, 27, pp. 82, 260.

tation test in skilled hands has been abundantly demonstrated. The substance that reacts with the precipitin ("precipitinogen") seems to persist indefinitely in dried blood; mixture with other bloods does not invalidate the reaction. While the blood precipitins are highly specific, they may produce a slight reaction with the sera of animals biologically related. The phenomenon of blood precipitation has been utilized by Nuttall and others for the purpose of throwing light upon the biologic affinities of forms of animal life.* Nuttall has established the interesting fact that the precipitin produced by human blood will throw down a more abundant precipitate from the blood of the old-world monkeys than from that of the South American species.

The precipitation test has also been applied to the differentiation and identification of meats. By its aid horse meat, for example, may be distinguished from beef.

The phenomena of precipitation and agglutination are essentially the same. Both appear to depend upon the facts that bacteria and colloid substances are kept in suspension in a fluid by charges of negative electricity, that the amount of negative electricity that the particles carry is reduced in some way by the substances known as agglutinins and precipitins, and that then the salts present in the fluid are able to neutralize the electrical charges so that the particles cling together and fall out of suspension.

(*c*) **Anaphylaxis.**—The term *anaphylaxis* (Gr., against protection) is applied to a state of excessive susceptibility which is induced in animals by the injection of certain substances. This condition, also known as "supersensitiveness" or "hypersusceptibility," may be brought about by the introduction into the body of a variety of protein substances, such as blood-serum, egg-white, milk, and also bacterial proteins and vegetable albumins. Attention was first drawn to the reaction by Otto,† following observations and suggestions made by Theobald Smith. The reaction was also observed independently by Rosenau and Anderson.‡ The "serum

* The subject of precipitation is treated with great clearness and fullness in a monograph by Nuttall, "Blood Immunity and Blood Relationship," Cambridge, Eng., 1904.

† Otto: Leuthold-Gedenkschrift, 1906, 1, p. 153.

‡ Rosenau and Anderson: Bull. 29, Hyg. Lab., Mar. Hosp. Service, 1906.

disease" which sometimes follows the injection of antitoxic horse serum and was the subject of detailed study by Pirquet and Schick* belongs to the same group of phenomena. The tuberculin and mallein reactions are other well-known instances of anaphylaxis. A definite period must always elapse between the first and second injection in order that the toxic effect shall be manifested. In the sensitization of guinea-pigs against horse serum, this period, as a rule, is from ten to twelve days. The toxic action of the horse serum upon the guinea-pig has been studied with especial fullness.† Sensitization may be effected by very small quantities; Rosenau and Anderson have reported that in one instance $\frac{1}{1,000,000}$ c.c. of horse serum was sufficient to render a guinea-pig susceptible. Larger doses, usually from 3 to 6 c.c., must be given in the second injection in order to produce a fatal result, but so small a quantity as $\frac{1}{10}$ c.c. may sometimes suffice to produce serious symptoms. The liability to react hypersensitively is transmitted from mother to offspring, the young of actively sensitized female guinea-pigs being themselves hypersensitive. The male does not transmit this quality. The anaphylactic reaction depends upon the development of a special antibody; passive hypersensitiveness may be induced by transfer of serum from a sensitized animal to a normal one.

Vaughan and Wheeler ‡ explain the phenomena of anaphylaxis by supposing that when a protein such as egg-white is injected, it is broken up into a toxic and a non-toxic component by an enzyme which is present in small amount in the animal body. At the first injection the disintegration takes place slowly and the organism is slightly or not at all affected. By the time the second injection is given, however, considerably larger quantities of the splitting enzyme have been elaborated, so that the liberation of a large amount of the toxic component is immediately brought about and produces sudden death.

Lewis § gives the following explanation in terms of the receptor theory: "As I would state it provisionally, there is in horse serum

* Pirquet and Schick: "Die Serumkrankheit," Vienna, 1905.

† Rosenau and Anderson: Bulls. 29, 30, 36, Hyg. Lab. Mar. Hosp. Service; Jour. Infect. Dis., 1905, 5, pp. 85–105.

‡ Vaughan and Wheeler: Jour. Infect. Dis., 1907, 4, p. 476.

§ Lewis: Jour. Exper. Med., 1908, 10, p. 24.

a substance which is actually a mild and potentially a severe toxin for the somatic cells of the guinea-pig. It is actually a mild toxin because the receptors to link the toxic substance to the cells are almost wanting. By the introduction of a minimal amount of this substance the few receptors normally present are exhausted, and subsequently regenerated in great excess. They can now be transferred passively either from mother to offspring or mechanically with the blood-serum. When the intoxicating dose of serum is injected, a relatively large amount of the toxin can now be suddenly brought in contact with the susceptible cells, and the acute reaction is developed. It must be remembered that this is a case in which the substance involved is not toxic for cells essential to the life of the animal when gradually administered, but only becomes so when it is suddenly introduced in excess."

CHAPTER IX

THE STAPHYLOCOCCI

The bacteria most commonly found in boils, abscesses, carbuncles, and similar suppurative processes in man belong to the group of staphylococci. The presence of staphylococci in pus was first shown by Pasteur * (1880) and later by Ogston † (1881). Micrococci were obtained in pure culture by Becker ‡ in 1883, but their causal relation to the suppuration of wounds and to osteomyelitis was first clearly brought out by the work of Rosenbach§ in 1884.

Several races or varieties of staphylococci have been differentiated in the course of later investigation. One of these, Staphylococcus (pyogenes) aureus, is found frequently in connection with pathologic processes in man; the other varieties, although very similar, differ in slight particulars from this type. Staphylococcus (pyogenes) albus, for example, is distinguished from Staphylococcus (pyogenes) aureus by its failure to produce a golden-yellow pigment.

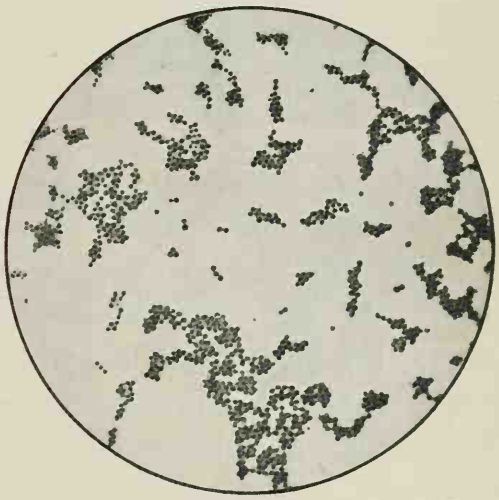


Fig. 30. — Staphylococcus aureus. Fuchsin; × 1000 (Günther).

Morphology and Staining. —The cells of Staphylococcus aureus are generally aggregated in loose, irregular masses which have been likened to clusters of grapes, and have given the generic name to this organism (Fig. 30). The dimensions of the individual cocci vary within rather narrow limits,

* Pasteur: Bull. de l'Acad. de Méd., 1880, 9, p. 447.

† Ogston: Brit. Med. Jour., 1881, 1, p. 369.

‡ Becker: Deut. med. Wchnschr., 1883, 9, p. 665.

§ Rosenbach: Mikroorganismen bei d. Wundinfektionskrankheiten, Wiesbaden, 1884.

the diameter of the cells ranging between 0.7 μ and 0.9 μ. The ordinary anilin dyes stain the cells readily; no decolorization occurs with Gram's method. In a preparation made directly from pus or from a pure culture, not only irregular clusters of cells can be observed, but also tetrads, diplococcus forms, and short chains. It is hence often difficult to determine from stained preparations whether only true staphylococci are present or whether there is an admixture of streptococci or other forms.

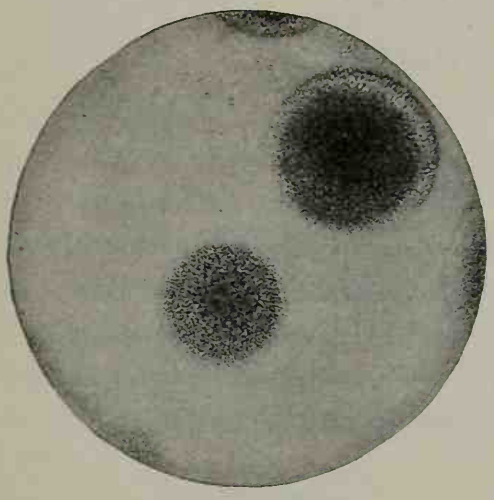


Fig. 31.—Staphylococcus aureus: colony two days old, seen upon an agar-agar plate; × 40 (Heim).

Physiologic Requirements.—The optimum temperature is about 28° C., but growth can also take place at temperatures as high as 42° C., and as low as 8° to 9° C. The cocci thrive best in the presence of oxygen, but grow to some extent under anaërobic conditions. As regards choice of culture-medium, this organism is not so fastidious as many other pathogenic bacteria (Fig. 31). It grows upon the ordinary laboratory media, and also, although less luxuriantly, upon protein-free media containing creatin or asparagin as the source of nitrogen (Fig. 32). The golden-yellow pigment which distinguishes the *aureus* variety from other staphylococci is formed in especial abundance upon blood-serum or upon a starchy medium, such as potato or rice. The thermal death-point is not constant, different strains appearing to vary greatly in their resistance, some succumbing only after thirty minutes' exposure to a temperature of 80° C., while others are destroyed within the same time at a much lower temperature. Considerable resistance is displayed toward drying, experiments showing a retention of vitality

Fig. 32.—Staphylococcus pyogenes aureus, gelatin stab-culture; four days.

for many days and even months, in cultures dried upon silk threads and desiccated over calcium chlorid. Toward the chemical substances ordinarily used as disinfectants Staphylococcus aureus also exhibits more than the average resistance. It is, indeed, one of the hardiest of the non-spore-forming bacteria.

Staphylococcus aureus is a well-nigh constant inhabitant upon the surface of the skin and also upon the various mucous surfaces of man and other animals. Apart from its occurrence in the air of hospitals, stables, and similar situations where its presence is readily explicable, it is found relatively infrequently in nature except in association with the animal body.

Products of Growth.—The golden-yellow pigment which is produced by this organism and which is probably a lipochrome, is formed most abundantly upon carbohydrate media and in the presence of free oxygen. A specific gelatin-liquefying enzyme or gelatinase is formed in gelatin and broth cultures and has been separated from the cultures by filtration. Other enzymes, such as rennin and maltase, are produced under suitable conditions. Milk inoculated with staphylococci is coagulated by the acid resulting from the fermentation of the milk-sugar; the precipitated casein, as a rule, remains undissolved.

Certain strains when grown under suitable conditions produce a substance that acts upon the stroma of red blood-corpuscles in such a way as to cause the dissolving out of the hemoglobin. This hemolytic substance is formed both upon agar plates and in broth cultures. The hemolytic qualities of filtrates of Staphylococcus aureus have been especially studied by Neisser and Wechsberg.* The specific hemolysin, known as staphylolysin, is completely destroyed by heating for twenty minutes at 56° C. An antibody to staphylolysin is produced by inoculating an animal with hemolytic filtrates, and there is other evidence that staphylolysin possesses a structure analogous to that of diphtheria toxin and is endowed with a stabile haptophore and a labile toxophore group. Many observers claim that a direct relation exists between virulence and hemolytic power, but others have failed to discover any such connection.

A substance that kills leukocytes is also present in staphylococcus filtrates; this has been termed leukocidin, and, like staphylolysin,

* Neisser and Wechsberg: Zeitschr. f. Hyg., 1901, 36, p. 330.

is a true toxin. The presence of leukocidin may be determined by an ingenious method devised by Neisser and Wechsberg, which consists in using the reduction of methylene-blue that is effected by live leukocytes as a measure of the integrity of the latter. The extent of retardation or disappearance of the reducing action measures the degree of injury wrought upon the leukocytes by the leukocidin.

From the physiologic effects which follow the injection of staphylococcus filtrates or cell-substance it is inferred that, besides the hemolysin and leukocidin, other toxic bodies are generated by these organisms, but practically nothing is known of the nature of these bodies. Cocci killed by heat can still provoke pus-formation.

Pathogenicity for Man.—Experiments, as well as the facts of comparative pathology, show that man is more susceptible than the ordinary laboratory animals to staphylococcus infection. Garré (1885) * inoculated himself by rubbing a pure culture upon the uninjured skin of the forearm, with the result that a series of carbuncles was produced, seventeen scars remaining to testify to the success of the experiment. His experiments have been repeated and confirmed by other observers (Bockhart,† Kaufman ‡). The penetration of the cocci into the deeper layers of the intact skin, probably through the sweat-ducts or at the base of the hair-follicles, is a fact of considerable significance. The positive occurrence of such penetration seems well established, and the negative observations of some authors may well be referred to differences in the virulence of the strains employed or to other experimental discrepancies.

The demonstration that staphylococci have power under certain circumstances to penetrate the skin, taken together with their practically constant presence upon the skin itself, serves to explain the multiplicity of human affections with which these micro-organisms are found associated. A momentary weakness on the part of the tissues in almost any locality may lead to a rapid local invasion, followed by the production of a simple boil or by a more or less

* Garré: Fortschr. d. Med., 1885, 3, p. 165.

† Bockhart: Baumgarten, Lehrbuch der path. Mykologie, Braunschweig, 1890.

‡ Kaufmann: Baumgarten's Jahresb., 1900, 16, p. 110.

extensive carbuncular condition. Septicemia and pyemia sometimes result through the introduction of staphylococci into the lymphatics or the blood-stream from a local abscess. The localization of the secondary foci varies in different cases. In the series of cases studied by Otten * 25 per cent. developed endocarditis. Sometimes general sepsis ("staphylomycosis") results from the most trivial local focus, such as a small boil or slight skin wound.

Staphylococci are not only found frequently in all parts of the body in secondary and mixed infections, but they are also primarily responsible for a variety of specific pathologic conditions and for injury to particular organs. Many lesions and diseases of the skin have been attributed to staphylococci; in the case of some of these it has been claimed that special varieties or races are concerned, but the characters said to distinguish these from the ordinary Staphylococcus aureus or albus are not, as a rule, of differential value.

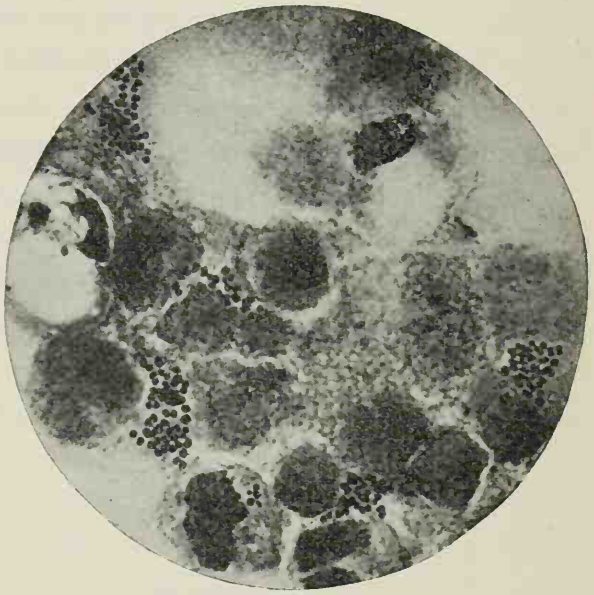


Fig. 33.—Staphylococcus aureus in pus from human abscess. Fuchsin stain; × 1000 (Fränkel and Pfeiffer).

A considerable majority of all attacks of acute osteomyelitis and periostitis are due to staphylococci, which appear to have a special predilection for the tissues of the osseous system.

Suppurative inflammation,† in whatever part of the body it may occur, is usually attended with the presence of staphylococci either in pure or mixed cultures (Fig. 33). Sometimes when found

* Otten: Dtsch. Arch. f. klin. Med., 1907, 90, p. 461.

† Suppurative inflammation is characterized particularly by the greatly increased immigration of the polymorphonuclear leukocytes into the affected part, by the lack of any coagulating power in the fluid portion of the pus (absence of fibrinogen), and by the necrosis and subsequent more or less complete digestion of the neighboring tissue elements.

in a mixed infection they are doubtless the original exciting cause; in other cases they may have arrived at the seat of trouble only after a primary invasion by some other microbe. In a given instance it may be impossible to determine the precise sequence of events.

Pathogenicity for Other Animals.—The rabbit has proved one of the more favorable animals for experimentation, intravenous injection of broth cultures being the most successful mode of infection. A moderately virulent strain kills an average-sized rabbit in four to eight days after injection of $\frac{1}{10}$ c.c. of a one-day broth culture (Neisser and Lipstein*). On autopsy minute abscesses are found in various internal organs, most commonly in the kidney (especially in the cortex of this organ) and in the walls of the heart. Under ordinary conditions of experiment with healthy adult rabbits the bone-marrow and periosteum are rarely seriously affected. In young animals, however, several experimenters claim to have evoked typical osteomyelitis by intravenous injection of staphylococcus cultures. It is perhaps questionable whether in these cases the processes in the affected tissues are strictly comparable with natural osteomyelitis in man. The injection of cultures into a rabbit suffering from a fractured bone or an injured periosteum produces a more characteristic train of events, and one that resembles closely the course of human osteomyelitis. Rabbits are relatively insusceptible to peritoneal inoculation with staphylococci. Artificial inoculation of the eye, on the other hand, succeeds readily, although natural eye infection is never observed. Feeding experiments with staphylococci give negative results. White mice are sometimes used for inoculation experiments, but are less uniformly responsive than rabbits; guinea-pigs are relatively resistant, rats and pigeons highly so.

Cases of spontaneous staphylococcus infection among domestic animals, while not so common as in man, are not unknown. In horses and cattle Staphylococcus aureus has been found associated with pathologic processes and conditions similar to those that it produces in human beings. Some observers believe that they have discovered special species of staphylococci in certain animal affections, *e. g.*, "Staphylococcus (pyogenes) bovis" (in cattle) and "Staphylococcus hæmorrhagius" (in sheep). Typical strains of

* Kolle and Wassermann, Handbuch, 3, p. 126.

Staphylococcus aureus and albus have been isolated from spontaneous abscesses in birds.

Varieties of Staphylococci.—According to a number of observers, agglutination experiments point to the existence of at least two races of staphylococci that may be distinguished as "pathogenic" and "saprophytic." The serum of animals injected with the saprophytic race has a much higher agglutinative power for the saprophytic races than for the pathogenic variety, and conversely. In nearly all other respects the two races are almost identical, although most observers agree that only the pathogenic race produces hemolysin and leukocidin.

The occurrence of a colorless variety, Staphylococcus (pyogenes) albus, has already been mentioned. This organism is identical in biologic qualities, in rapidity of growth, in pathogenicity, and, in fact, in all respects except pigment-production, with the aureus variety. On these grounds bacteriologists have been tempted to regard the unpigmented form as a degenerate descendant of the pigmented strain; but attempts to transform one variety into the other have not as yet succeeded. An interesting race of the albus variety (Staphylococcus epidermidis albus, Welch) is found in the deeper layers of the human skin, where it is not reached by ordinary methods of disinfection. It is of relatively slight virulence, and is the cause of the "stitch abscesses" following certain surgical proceedings. The ordinary Staphylococcus albus type is found not uncommonly in abscesses in man, sometimes in pure culture, more often in conjunction with the aureus variety. Staphylococcus (pyogenes) citreus is a rarer form of doubtful pathogenicity, producing a lemon-yellow pigment, but in other respects standing close to Staphylococcus aureus. Two varieties of staphylococci still more infrequently met with in human pathology are Staphylococcus cereus albus and Staphylococcus cereus flavus; these forms do not liquefy gelatin, and produce a wax-like growth on the surface of the medium.

Immunity.—Rabbits may be made actively immune against intravenous injection with staphylococci by inoculating them first with killed, then with living but attenuated, cultures. During the course of this treatment, however, the animals sometimes succumb, and it is evident that the incorporation of staphylococcus cells into the

body is attended with some danger to the subject of experiment. If filtrates containing staphylococcus hemolysin and leukocidin be used, antibodies for these toxins are formed; but immunity certainly does not depend upon the presence of these antibodies, since no connection has been shown to exist between increased resistance and the presence of such antibodies in the blood. Neither does prolonged immunization with the staphylococcus cells and their products cause any appreciable increase in the amount of bacteriolytic substance.

The production of active immunity to staphylococcus is, however, accompanied by a striking development of phagocytic action. Phagocytosis unquestionably plays the chief rôle in immunization to this organism. Staphylococci injected into an immunized animal are much more rapidly taken up by the phagocytes than is the case in a normal animal. Such increased phagocytosis, again, has been shown by Wright and others to be connected with the formation of bacteriotropic substances or opsonins in the blood of immunized animals. Methods of treatment based upon the increase in the amount of opsonin, and carried out by inoculation with a "vaccine" consisting of three-weeks-old broth cultures, killed by heating at 60° C. for an hour, have been very successfully applied by Wright and others to the treatment of obstinate cases of acne and furunculosis in man. Hartwell and Lee,* for example, conclude that treatment with vaccine is the most effectual remedy for boils and carbuncles and for cases of chronic furunculosis. These authors state that the vaccine treatment can be successfully carried on without estimation of the opsonic index, but others maintain that it should not be used without accurate opsonic control.

Injection of the serum from an immunized animal will protect untreated animals against infection; in this case, also, the acquired immunity (passive) seems to be associated with an increase in the amount of opsonin.

* Hartwell and Lee: Bost. Med. and Surg. Jour., 1907, 157, p. 523.

CHAPTER X

THE STREPTOCOCCI

Streptococci, as well as staphylococci, were seen long ago by several observers in the pus formed during suppurative inflammation, but their constant presence and pathologic significance were first strongly emphasized by the work of Ogston (1881),* Fehleisen (1883),† and Rosenbach (1884). ‡ Owing to the great variety of pathologic conditions with which streptococci are found associated, some perplexity has been caused as to whether the various conditions are due to one or to several species. Cultures of streptococci from erysipelas ("Streptococcus erysipelatis," Fehleisen), for example, were long kept separated in bacteriologic laboratories from cultures obtained from various suppurative processes (Streptococcus pyogenes). While in this particular case further investigation has tended to obliterate any sharp distinctions between erysipelas streptococci and suppurative streptococci, the question of the existence of different races cannot be regarded even yet as definitely settled. At present Streptococcus pyogenes is employed sometimes as the name of a species, sometimes as that of a group of micro-organisms.

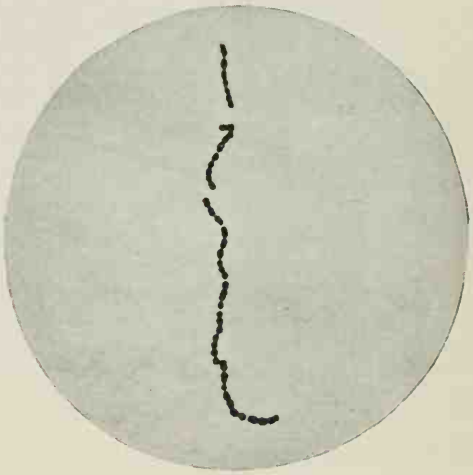


Fig. 34.—Streptococcus pyogenes. Pure culture in bouillon. Fuchsin stain; × 1000 (Kolle and Wassermann).

Morphologic and Cultural Characters.—The cells of streptococcus, like those of staphylococcus, are spherical, but differ

* Ogston: Brit. Med. Jour., 1881, 1, p. 369.

† Fehleisen: Aetiol. d. Erysipels, Berlin, 1883.

‡ Rosenbach: Mikroorganismen bei d. Wundinfektionskrankheiten, Wiesbaden, 1884.

from those of the latter organism in being usually united in longer or shorter chains (Figs. 34 and 35). Under certain conditions, however, they are aggregated in irregular heaps or masses. The diameter of the individual cocci is about 1 μ, although some variation is noted according to the character of the culture-medium, and smaller cells are not rare. The typical streptococcus always divides in one plane, so that if the cells remain united, a typical chain results. Transition forms between this and the staphylococcus have, however, been observed. Streptococci are not motile under the ordinary conditions of observation, do not possess flagella, and do not form spores. The streptococci isolated from pathologic processes in man retain the stain by Gram's method, but some streptococci found in suppurative conditions in domestic animals are said to be Gram-negative.

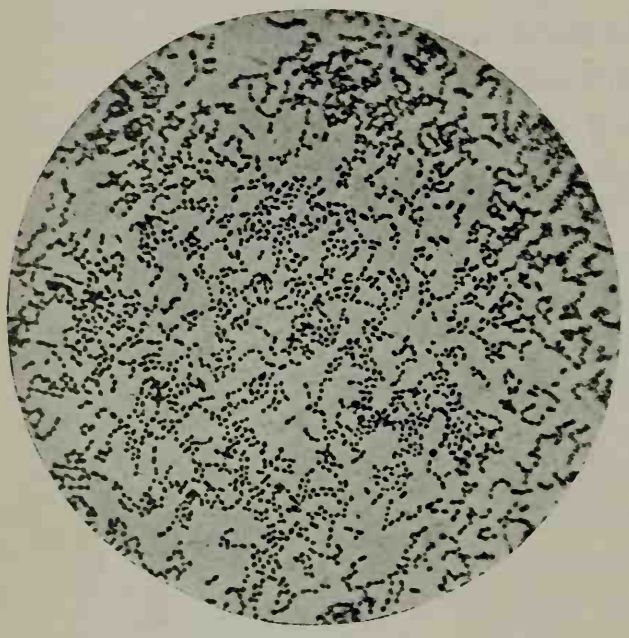


Fig. 35.—Streptococcus, pure culture (Moser and v. Pirquet).

In the opinion of some investigators an important distinction should be drawn between long-chain (Streptococcus longus) and short-chain (Streptococcus brevis) streptococci. The former are thought to be more virulent, and, as a matter of fact, the streptococci freshly isolated from disease processes in man usually grow out into long chains (of more than eight cells), while saprophytic streptococci, such as are commonly met with in the normal mouth and throat, develop short chains. Other morphologic and biologic qualities are believed to correspond. It has been found possible, however, to transform the long-chain into the short-chain variety by alteration of the culture-medium, and, furthermore, short-chain streptococci which are virulent are sometimes isolated from pathologic cases. As an

absolute distinction, therefore, any fundamental separation into Streptococcus longus and Streptococcus brevis breaks down, but as calling attention to a generally valid correlation-character, the names have some value.

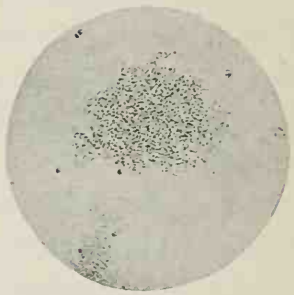


Fig. 36.—Streptococcus pyogenes. Colony on glycerin-agar, one day; × 100 (Heim).

Upon ordinary nutrient agar and gelatin streptococci, as a rule, yield but a scanty growth of fine, transparent, separate colonies (Figs. 36 and 37). Development is much facilitated, however, by the addition of dextrose (0.5 to 1.0 per cent.) to the medium. The common pathogenic strains do not liquefy gelatin, but some of the saprophytic streptococci, isolated from the alimentary tract and from polluted water, possess liquefying power. The growth in broth varies in different specimens; it is sometimes fine and powdery, sometimes coarse and flocculent. The character of the sediment that collects at the bottom of a broth culture has been supposed to give some indication of the essential nature of the organism producing it. Differentiation on this basis has not, however, been generally accepted. It is true that the long-chain forms usually give rise to distinct granules (Streptococcus conglomeratus), but it has not yet been shown that an invariable diagnostic value can be attached to the characters of broth cultures. Blood-agar plates, made by adding 1 c.c. of fresh or defibrinated blood to 6 c.c. of agar at 40° to 45° C., are useful for the differentiation of streptococci. When such plates are inoculated with characteristic streptococci and incubated for twelve to twenty-four hours, small colonies of streptococci appear, each surrounded with a clear zone due to hemolytic action. Pneumococci and related organisms, on the other hand, produce a green coloration. Blood-serum (horse, man) diluted with broth, or un-

Fig. 37.—Streptococcus pyogenes. Agar culture, two days, showing colonies (Fränkel and Pfeiffer).

diluted (rabbit), is a favorable medium for the maintenance of vitality and virulence. Growth occurs in milk, and in many strains is followed by curdling due to fermentation of the lactose, but some strains, particularly the long-chain varieties, generate too little acid to effect any visible change. Upon potato a more or less luxuriant growth is produced by most saprophytic forms, but the pathogenic varieties develop sparingly, and many refuse to grow at all. The preservation of streptococcus cultures, often a matter of some difficulty, is best effected by maintaining either serum-broth mixtures or gelatin stab-cultures at a low temperature (8° to 10° C.).

Virulence; Toxin Production; Hemolysin.—The virulence of different strains of streptococci varies widely, but the factors upon which such virulence depends have not been discovered. Virulence for one species may be greatly exalted by animal passage; at the same time the virulence of the same strain for another species may be diminished. There is evidence that streptococci which are isolated directly from septic processes in man are more dangerous to man than similar organisms which have been living as saprophytes on the skin or mucous membrane. As a rule, growth within an animal body enhances the virulence of a microbe for that particular species, and this seems to be especially true in the case of the bacteria of blood-poisoning (streptococci and staphylococci).

The cell-substance of streptococci possesses only slight toxicity. and virulent strains do not differ from avirulent in this respect.

Old filtrates are more or less toxic, but no powerful specific toxin has been demonstrated. It is possible that certain poisons are formed by streptococcus in the living body which are not produced in cultures.

A specific hemolysin, streptolysin, has been demonstrated by Besredka,* Ruediger, and others. According to Ruediger,† streptolysin is a true toxin, containing a haptophore and a toxophore group, and giving rise, on injection, to a specific antibody. There is no good evidence that this hemolytic substance bears any constant relation to the virulence of the micro-organism producing it, or that it plays any part in producing the pathologic conditions caused by streptococcus infection.

* Besredka: Ann. de l'Inst. Past., 1901, 15, p. 880.

† Ruediger: Jour. Amer. Med. Assoc., 1903, 41, p. 962.

Pathogenicity for Man.—Few, if any, pathogenic organisms can lay claim to wider or more multifarious activities than the streptococcus. The list of human diseases and affections with which streptococci are associated as the main and primary cause is already a long one, and is perhaps not yet complete. In addition to their conspicuous rôle as initiators of very diverse pathologic conditions, streptococci are present in "mixed infections" and "secondary infections" more often than any other microbes; that is to say, they have a tendency to follow in the wake of and act as accomplices to other pathologic organisms. It has been found from an examination of the heart's blood of cadavers that in about one-third of all fatal diseases streptococci invade the blood before death, and in these cases they perhaps aid more or less in facilitating a fatal termination.*

The pathogenicity of streptococcus for man is well exemplified in erysipelas. This peculiar inflammation of the skin was shown by Fehleisen in 1883 to be due to streptococci. The cocci are not present in the central portion of the inflamed area, but are found on its periphery, and can be isolated most readily by excision of portions of the tissue, other methods rarely succeeding. In the skin they occur chiefly in the lymph-spaces, which are often packed with them. Inoculation experiments made upon carcinomatous patients† have demonstrated not only that pure cultures of erysipelas-streptococci can provoke the erysipelatous process, but also that streptococci isolated from non-erysipelatous conditions may give rise to erysipelas in certain persons. Petruschky‡ in this way produced erysipelas by inoculation with a streptococcus cul-

* Simmonds: Virchow's Archiv, 1904, 175, p. 418.

† Clinical observers have often noted that patients suffering from malignant tumor were distinctly benefited by an attack of erysipelas, that the growth was checked, and the tumor even diminished in size. Acting on this observation, Fehleisen ventured to inoculate streptococci into persons suffering from inoperable tumors, and the experiment was apparently rewarded with some degree of therapeutic success. Coley (Amer. Jour. Med. Sci., 1896, 112, p. 251) has modified the treatment by employing a mixture of killed cultures of streptococci and B. prodigiosus, or the soluble products of these organisms. In all cases where an injection of dead or living streptococci has seemed to exercise a favorable influence, the sarcomatous tumors are most affected, the carcinomatous tumors being only slightly and temporarily inhibited. Many observers have been unable to note any favorable results following upon the use of "Coley's mixture."

‡ Petruschky: Zeitschr. f. Hyg., 1896, 23, p. 142.

ture isolated from the pus obtained from a case of puerperal infection. The natural occurrence of erysipelas in the human subject appears to depend upon two factors; first, upon an individual disposition to contract erysipelas, a characteristic which is often marked in certain families; and, second, upon a probably not very high degree of virulence on the part of the infecting micro-organism.

The epidemiologic relations between erysipelas and puerperal fever were noticed by several acute observers before the discovery that one and the same specific germ could produce these affections, and, indeed, before bacteria of any sort had been shown to cause disease. The possibility of transfer of erysipelas streptococci to puerperal cases has long been recognized. The combined evidence of observation and experiment has caused the abandonment of the view once held by bacteriologists that Streptococcus erysipelatis and Streptococcus pyogenes are distinct species.

Fig. 38.—Streptococcus pyogenes in pus from a human abscess; gentian-violet (Fränkel and Pfeiffer).

Besides causing typical erysipelas, streptococci sometimes give rise to other affections of the skin and lymph-vessels (*e. g.*, impetigo contagiosa*).

Many *suppurative inflammatory conditions* in different organs of the body are caused by streptococci (Fig. 38). Osseous tissues and tissues surrounding the bones are attacked less frequently by streptococci than by staphylococci, but the joints and serous membranes are often invaded.

Pneumonia is sometimes due to a primary streptococcus infection.

Ulcerative endocarditis, an affection of the valves of the heart, which occasionally occurs simultaneously with inflammatory conditions in other parts of the body, is produced most frequently

* Kurth: Arb. u. d. k. Ges., 1893, 8, p. 294.

by streptococci, although it may also be caused by staphylococci, and less commonly by other micro-organisms. Experimentally the injection of broth cultures of streptococci (or staphylococci) into the circulation rarely produces ulcerative endocarditis unless the cardiac tissues have been damaged by mechanical or chemical agencies.

Süpfle* has found streptococci much more abundant than any other micro-organism in inflammation of the middle ear (otitis media).

The mucous membranes constitute a favorite abiding-place for streptococci: the tonsils almost always harbor them. Consequently any lowering of the normal resistance of these tissues from either local or general causes gives the signal for a speedy invasion. In throat affections of all sorts streptococci are usually present, and in some cases, notably in diphtheria and in the anginas of scarlatina and measles, the part played by these organisms is highly important. Typical diphtheria is so generally accompanied by a multiplication of throat streptococci that at one time these micro-organisms were regarded as the cause of diphtheria. While there is no longer any support for this extreme view, it is true that, in addition to the local injury that may be done to the throat by the streptococci, especially in the production of the false membrane, the virulence of the diphtheria bacillus itself seems in some degree to be exalted by the presence of streptococci.

The majority of non-diphtheritic anginas, in the opinion of many observers, are due directly to streptococcus infection. It cannot be said, however, that this position is entirely justified, since the facts are open to the interpretation that the streptococci found in simple anginas are merely secondary invaders which, as in diphtheria, have followed in the train of some primary infecting agent.

The septicemic condition known as puerperal fever, which is sometimes a sequel of childbirth, is usually to be attributed to streptococci. The once common hospital epidemics of puerperal septicemia, which fill so grim a page of medical history,† were

* Süpfle: Centralbl. f. Bakt.Orig., 1906, 42, p. 304.

† As long ago as 1843 Oliver Wendell Holmes published (New Eng. Quar. Jour. of Med. and Surg., April, 1843) an essay on the contagiousness of puerperal fever in which he marshals a surprising array of cases of this disease that were evidently carried to the mother by the attending physician or nurse

probably due to the manipulative transfer of streptococci from infected cases; but it is also supposed that in some cases auto-infection occurs. Most observers agree that streptoccocci are found in the vaginal secretions of pregnant women, especially when the secretions are alkaline. The prevailing opinion is that infection may take place with germs from any portion of the genital tract, including the external parts, and that special care should be given to the disinfection of the external genitalia before and during birth.

Certain cases of enteritis in infants and occasionally in adults have been attributed to streptococci (Escherich et al.). There is little doubt that streptococci, if not the primary cause of intestinal disturbance, are at least actively concerned in the pathologic processes. Several varieties of intestinal streptococci have been described, separable from one another and from the ordinary Streptococcus pyogenes by more or less definite cultural characteristics; but the evidence showing a connection of any particular variety with the causation of intestinal disease is not as clear as could be desired. Intestinal infection of infants might conceivably occur through the medium of the milk-supply, since streptococcic inflammation of the mammæ (mastitis) of the cow is not uncommon. Streptococci have been often found in market milk, but it has not been shown that their presence, even in considerable numbers, is any indication that the milk is unwholesome. Most of the streptococci in milk are probably descended from saprophytic, not from pathogenic, ancestors. (See p. 472.)

As a secondary invader streptococcus has a baneful influence upon a number of maladies, notably upon the last stages of pulmonary tuberculosis, where it produces frequent complications, involves healthy tissues adjacent to the tuberculous area, and predisposes to hemorrhages. Streptococci are often present also in pneumonia as a mixed infection, and in some cases act as the primary cause.

Some years later Semmelweiss, in 1861 ("Die Aetiologie, der Begriff und die Prophylaxis des Kindbettfiebers," Pest, Wien u. Leipzig, 1861), showed clearly that puerperal mortality could be greatly reduced by attention to cleanliness, especially of the instruments and hands of the operator, but his teachings were for a long time neglected and even scorned. During the period before aseptic and antiseptic methods came into use in lying-in hospitals infection was conveyed from one case to another, and in some years nearly all the patients that entered a given hospital would die soon after being delivered of child.

In smallpox and in scarlatina many of the most serious symptoms and most frequent complications are the result of streptococcus infection. In these diseases streptococci can be isolated from the internal organs in a large percentage of the fatal cases, and in some instances they can be isolated from the blood during life. Some bacteriologists maintain that streptococci are the cause of scarlatina, but this view is not generally accepted.

Rheumatic fever or acute articular rheumatism has been attributed by different observers to various kinds of bacteria. An anaërobic bacillus found by Achalme* was at one time regarded by some writers as the cause of this affection, but Achalme's bacillus is probably identical with B. welchii (p. 326) and has no causal relation to rheumatism. Streptococci have been found in the blood in a number of cases of rheumatic fever, and characteristic arthritic lesions have been produced in rabbits by inoculation with cultures derived from such cases. By some observers the streptococci (or diplococci) from acute rheumatism have been considered different from the ordinary Streptococcus pyogenes. Several investigators, however, have produced experimental arthritis in rabbits with streptococci from non-rheumatic sources (Cole †). At the same time the work of Poynton and Paine,‡ Beattie,§ and others deserves attention, and it is possible that Streptococcus (or Diplococcus) rheumaticus will eventually come to be regarded as an independent species. According to some investigators, distinctive and constant cultural characters, such as the production of acid and precipitation of bile salts in McConkey's bile-salt-lactose-broth, and abundant production of formic acid (Walker and Ryffel) ||, characterize the micrococcus found in rheumatism. For the present the question of the specificity of the streptococcus found in rheumatism may be regarded as unsettled.

The removal of those useless appendages, the tonsils, which frequently serve as the portal of entry for streptococci, has been observed to have a favorable influence upon rheumatic patients. All these facts, however, do not exclude the possibility that in

* Achalme: Arch. de méd. Expér., 1898, 11, p. 370.

† Cole: Jour. Infect. Dis., 1904, 1, p. 714.

‡ Poynton and Paine: Centralbl. f. Bakt., 1902, 31, p. 502.

§ Beattie: Jour. Med. Res., 1905–06, 14, p. 399.

|| Walker and Ryffel: Brit. Med. Jour., 1903, 2, p. 659.

acute rheumatism, as in other diseases, streptococci simply play the rôle of secondary invaders, and that the real cause is yet undiscovered. Streptococcic septicemia may develop in connection with a great variety of affections, both those in which streptococcus itself is the initial exciting cause, and those that are set in motion by other factors. The *coup de grace* in many prolonged constitutional maladies, such as diabetes, is often given through a general streptococcus invasion.

Pathogenicity for the Lower Animals.—Among the lower animals streptococci are found in spontaneously produced abscesses and similar suppurative processes in about the same proportion as in man: they are less common than simple staphylococcus infections, but are said to comprise from one-third to one-fourth of all cases. Horses seem particularly subject to streptococcus infection. The streptococci found in inflammation of the cow's udder are said to differ from the streptococci of human inflammations in being gram-negative, in their ability to liquefy gelatin, and in their higher pathogenicity for guinea-pigs.

Experimentally, rabbits and mice have proved most susceptible to inoculation. There is an entire absence of correlation in the pathogenicity of streptococci for different animals. A culture isolated from a severe septic infection in man may be utterly devoid of pathogenic power for the mouse, while a culture obtained from a small localized abscess may be highly mouse-virulent. Virulence for a given species of animal, such as the mouse, may be exalted by successive passages through individuals of that species, but the greatly heightened virulence thus obtained for one animal (mouse) may be accompanied by the simultaneous diminution of virulence for another (rabbit) (Knorr *). On the other hand, passage through rabbits increases the virulence not only for the rabbit, but also for the mouse and for the larger domestic animals. Cultures whose virulence has been artificially exalted for the rabbit and the mouse appear to have lost much of their pathogenic power for man. Interpreted on the receptor theory, these facts indicate a considerable qualitative difference in the receptor endowment of the different animal species. Rabbits and mice usually develop a generalized infection when inoculated with virulent strains. One-millionth of a cubic centimeter of a twenty-four-hour-old broth culture has

* Knorr: Ztschr. f. Hyg., 1893, 13, p. 427.

been found to kill a rabbit, but such a high degree of virulence is rare except in artificially exalted cultures. As a rule, a culture is regarded as of fairly high virulence if $\frac{1}{100}$ c.c. kills a rabbit within three or four days. Slightly virulent strains may produce localized abscesses; an erysipelatous process has been provoked in the ear of the rabbit by the use of a culture of the proper degree of virulence.

One or Several Species of Streptococci?—One of the most vexed questions in the history of streptococcus infections has been that concerning the essential identity of the cultures isolated from various sources. Several phases of this matter have already been touched upon. It is a well-established fact that association with diverse pathologic conditions does not in itself afford an adequate basis for specific differentiation: streptococcus cultures isolated from suppurative processes in man are able to produce erysipelas, and vice versâ. A close examination of the morphologic and physiologic peculiarities of various strains has made it clear that more or less difference exists between certain cultures, but it is yet uncertain how much importance can be attached to these divergences as betraying a deep-seated difference. In fact, any uniformity in the observed differences in cultural characters has itself been called in question. On the other hand, it does not follow that production of similar symptoms and lesions is a mark of specific identity. There appears to be quite as much reason for enforcing a distinction between certain strains of streptococci as between the varieties of staphylococci long characterized by the names *aureus*, *albus*, *flavus*, and the like. Attempts to differentiate streptococcus groups by the agglutination test have not succeeded. The agglutination reaction, for example, between the streptococci cultivated from scarlatina and the serum from cases of this disease is in no way specific.* It is possible that future developments in technic may enable a more definite conclusion to be reached concerning the unity or plurality of streptococcus forms; it may even be questioned whether existing methods have been pushed as far as practicable in the solution of this problem. C. E. A. Winslow and Anne R. Winslow have made a special study of the classification of the micrococci.† These authors divide the cocci into two chief divisions, Metacoccaceæ and Para-

* Weaver: Jour. Infect. Dis., 1904, p. 91.

† The Systematic Relationships of the Coccaceæ, New York, 1909.

coccaceæ. The former are mostly saprophytes, grow best under aërobic conditions, and produce little or no acid from carbohydrates. They are commonly gram-negative and produce a yellow or red pigment. The latter are, for the most part, parasites, grow best under anaërobic conditions, and produce abundant acid from carbohydrate fermentation. They are usually gram-positive, and, except for some varieties which produce an orange pigment, are not chromogenic.

Immunity.—In man the immunity conferred by a natural streptococcus infection is probably never very high, and is relatively transient. There appears to be considerable individual variation. Fehleisen could not always produce a second attack of erysipelas in persons who had been once successfully inoculated, but Koch and Petruschky * were able to cause ten successive attacks in one individual in the same area of skin, a fresh inoculation being made each time immediately after an attack had subsided.

Animals can be immunized by the injection of filtrates of virulent cultures, or by the injection of dead, then attenuated, and finally virulent cultures. A high degree of immunity has been obtained by some observers (Marmorek,† Aronson‡) by inoculation with cultures rendered very virulent by passage through rabbits. Agglutinins are present in the blood of immunized animals (Fig. 39).

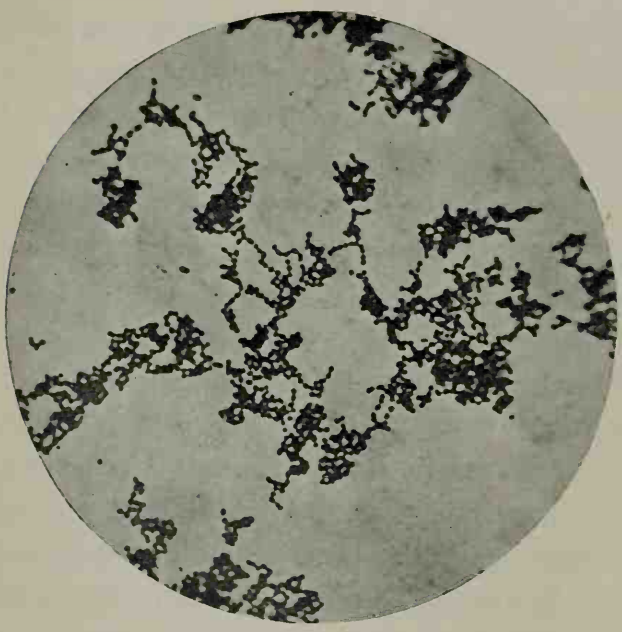


Fig. 39.—Streptococcus agglutinated by immune horse serum (Moser and v. Pirquet).

Neither antitoxic nor bactericidal substances are present in any noteworthy degree in the blood of immun-

* Petruschky: Ztschr. f. Hyg., 1896, 23, p. 477.

† Marmorek: Ann. de l' Inst. Past., 1895, 9, p. 593.

‡ Aronson: Berl. klin. Wochnschr., 1896, 33, p. 717.

ized animals. The phagocytes, however, display increased activity. Bordet* showed that pronounced phagocytosis of streptococci takes place in the peritoneal cavity of immune animals, while it is very slight in normal animals. The addition of immune serum to normal leukocytes in test-tube experiments causes the leukocytes to advance upon, engulf, and digest the streptococci. The marked increase of phagocytosis is probably due, as in other cases, to the development of a bacteriotropic substance or opsonin in the body-fluids of the immunized animals. The streptococcus opsonin is quite resistant to heat (62° to 65°) and also to acids and alkalis. According to Ruediger,† the amount of opsonin is sometimes increased during an attack of erysipelas.

The Use of the Serum of Immunized Animals for Protective and Curative Purposes.—Many attempts have been made to obtain an antistreptococcus serum which shall cure or prevent streptococcus infection in man. Marmorek,‡ by the use of streptococci made highly virulent for rabbits, 0.000,001 c.c. of a broth culture being fatal, has prepared a serum that has been rather extensively used both in animal experiments and in human therapeutics. The experiments of Marmorek and others leave no doubt that the serum of suitable horses that have been treated with these virulent cultures frequently exerts a marked protective influence when inoculated into a streptococcus-infected animal. In human infections conflicting results have been obtained: in some cases favorable effects have been noted, but on the whole the use of Marmorek's serum has been distinctly disappointing. Experiments with animals have shown that in some cases those sera prepared with a particular strain will protect against that strain, but not against streptococci derived from other sources. A similar serum prepared by Aronson, when given to a mouse in doses of 0.0004 to 0.0005 c.c., will protect the animal against ten fatal doses of streptococci, inoculated twenty-four hours after the serum. According to some observers, Aronson's serum has been successfully used in the treatment of scarlet fever and has reduced the mortality from this disease.

* Bordet: Ann. de l'Inst. Past., 1897, 11, p. 177.

† Ruediger: Jour. Infect. Dis., 1906, 3, p. 156.

‡ Marmorek: Ann. de l'Inst. Past., 1895, 9, p. 593.

The failure or very moderate success attending the use of Marmorek's and Aronson's sera has been attributed by certain investigators to the fact that these sera are "univalent,"—that is, prepared by the use of a single strain of streptococcus,—and attention is also directed to the fact that while the strains used are virulent for the rabbit, they are not necessarily so for man. In the endeavor to overcome these possible reasons for failure, Tavel, Moser,* and others have immunized animals by using a number of different strains of streptococci, and have especially aimed to employ strains recently isolated from pathologic conditions in man, and not altered by animal passage. The "polyvalent" sera obtained from such animals are alleged to give more satisfactory results than those prepared by the earlier methods. Moser,† who assumes that scarlet fever is a streptococcus disease, uses the serum of horses injected with about twenty different strains of streptococci cultivated from cases of scarlet fever, and maintains that such a serum has a strongly favorable influence upon patients suffering from this disease. A similar claim is advanced by Menzer‡ respecting the treatment of rheumatism with sera produced with streptococcus strains isolated from rheumatic patients. It must be admitted, however, that, on the whole, the evidence bearing on the therapeutic value of the various antistreptococcic sera is very far from conclusive. The mode of action of such sera, as has been shown, is still undetermined, and there are consequently lacking adequate methods of standardization and control. Hektoen and Ruediger§ found that the commercial streptococcic sera at one time in use in this country all possessed a lower opsonic index for various streptococci than normal horse serum. Since in animal experimentation the opsonin content of an antistreptococcus serum seems to be the factor that gives the serum whatever protective value it possesses, it is clear that the evidence of therapeutic success for such sera should be carefully sifted.

* Moser: Klin.-therap. Wchnschr., 1902, No. 28; Abs. Centralbl. f. Bakt., 1903, 32, p. 690.

† Moser: Wien. klin. Wchnschr., 1902, 15, p. 1053.

‡ Menzer: Die Aetiologie des akuten Gelenkrheumatismus, Berlin, 1902.

§ Hektoen and Ruediger: Jour. Am. Med. Assoc., 1906, 46, p. 1407.

CHAPTER XI

THE PNEUMOCOCCUS (STREPTOCOCCUS PNEUMONIÆ)

The micro-organism most commonly met with in acute inflammations of the lungs in man is a small micrococcus upon which a great variety of names have been bestowed; those in most general use are *Streptococcus* (or *Diplococcus*) *pneumoniæ*, *Micrococcus lanceolatus*, or, more briefly, the *pneumococcus*. It is also known, after its discoverer, as *Fränkel's pneumococcus*.

In considering the relations of this organism to the production of pneumonia, it must be borne in mind that the name pneumonia is not restricted to absolutely uniform changes in one set of tissues, but that writers group under this name a variety of affections symptomatically and histologically distinct. Among the most generally recognized of these are: lobar (acute croupous) pneumonia, bronchopneumonia or lobular pneumonia, and capillary bronchitis (bronchiolitis). If one of these anatomic types—for example, lobar pneumonia, the common form in adults—be considered from the etiologic standpoint, it is found that at the present time in temperate climates acute lobar pneumonia in the vast majority of cases is caused by a lanceolate micrococcus, occurring in pairs or chains—the pneumococcus of Fränkel. A number of other species of bacteria may occasionally also give rise to this condition. Among these are B. diphtheriæ (p. 229), B. pestis (p. 297), B. typhosus (p. 267), B. mucosus capsulatus (p. 260), and also streptococci and staphylococci. For the most part, however, the pneumonias produced by these species are of the lobular type. Pneumonia, then, is not a disease either of constant anatomic character or of uniform etiology. One and the same organism can incite affections histologically dissimilar, such as the lobar, lobular, and bronchiolitic forms, and, on the other hand, apparently identical lesions may be produced by the action of different microbes.

Morphologic and Cultural Characters.—Morphologically the pneumococcus is a small, slightly elongated coccus, one end of which is

pointed. It shows a marked tendency to occur in pairs (diplococci), although short chains are also seen not infrequently (Fig. 40), The resemblance to ordinary streptococci is often striking, but the chains are rarely as long as those formed by the true Streptococcus pyogenes. A well-defined capsule envelops the pneumococci in pathologic exudates (Fig. 41) and in the blood of inoculated animals, but, except in certain strains or in certain media, such as milk, the capsule is less evident or altogether wanting in cultures grown outside of the animal body. When treated by Gram's method, pneumococci retain the stain.

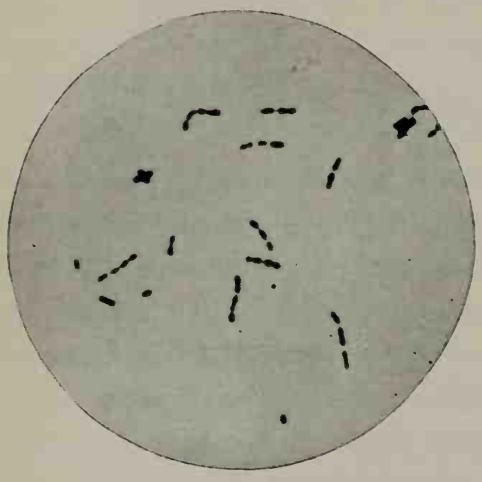


Fig. 40. — Streptococcus pneumoniæ in pure culture one day old. Gram stain. Weichselbaum prep. (Kolle and Wassermann).

Some pneumococci grow upon the ordinary culture-media, such as nutrient agar or gelatin, although never luxuriantly. Other strains, however, perhaps owing to their closer adaptation to a parasitic habit of life, grow with the greatest reluctance or cannot be cultivated at all. The character of the growth on various media closely resembles that of Streptococcus pyogenes. The presence of glucose or glycerin favors the growth of the pneumococcus, but the acid formed by the fermentation of these substances is injurious to continued vitality. Litmus milk is promptly acidified and coagulated; in this medium the cocci usually show a capsule. Specially prepared media, most of which contain human or animal sera, are used to advantage. One of the most

Fig. 41. — Streptococcus pneumoniæ in exudate from human lung; anilin-water-fuchsin; Weichselbaum prep. (Kolle and Wassermann).

useful of the solid media is that recommended by Weichselbaum, consisting of one part of human serum and two parts of nutrient agar. A very satisfactory fluid medium is that of Marmorek, which is composed of two parts of ordinary nutrient broth and one part of ascitic or pleuritic fluid. Blood-agar is one of the best media for conserving both vitality and virulence. The temperature range of the pneumococcus is narrow, growth taking place, as a rule, only between 27° and 42° C. Even upon the most favorable media the organism sometimes dies out very quickly. The vitality of cultures may, however, usually be conserved for some time in the refrigerator or maintained by frequent transfer (every two or three days). Cultures in Marmorek's medium have been found still living and virulent after eight months (Lambert). In dried pneumonic sputum the cocci may survive for as long as fifty-five days. Their life in dust and in the infectious droplets discharged into the air by coughing or sneezing probably does not extend over more than a few hours.

Varieties and Distribution.—It has been shown by several investigators that more or less distinct varieties of pneumococci exist, distinguishable from one another by their physiologic characters in cultures or by the effects that they produce in animals on inoculation. Especially are there found, both in normal mouths and in various pathologic conditions, so-called atypical pneumococci that resemble the true pneumococcus morphologically and in staining reactions, but are thought by some to be distinguished from it by their inability to ferment inulin* (Hiss †), and by their agglutination reactions. Streptococcus mucosus, an organism that is found in some cases of pneumonia, and that forms a great abundance of capsular material in cultures when first isolated, but which ferments

* Inulin-serum-water, prepared by mixing 1 part of ox serum, 2 parts of distilled water, and 1 per cent. of inulin, is usually fermented by Streptococcus pneumoniæ (and Streptococcus mucosus), with resulting coagulation of the serum; strains of Streptococcus pyogenes ordinarily met with do not ferment inulin. On the other hand, a morphologically typical strain of the pneumococcus has been found which does not ferment inulin. Considerable variation in inulin-fermenting power is shown by typical pneumococci, and too great reliance should not be placed upon this test. (See, for example, Jane Berry, Jour. Infect. Dis., 1907, 4, p. 93, and Buerger and Ryttenberger, Jour. Infect. Dis., 1907, 4, p. 609.)

† Hiss: Jour. Exp. Med., 1905, 6, p. 317.

inulin, is probably to be classed with the true pneumococci. Transition forms linking Streptococcus pneumoniæ with Streptococcus pyogenes have been described, and precise differentiation is often difficult. The full significance of all the varieties and intermediate forms remains to be elucidated.

Particularly important are the facts concerning the distribution of the pneumococcus. Few observations exist as to its occurrence in external nature, although it has been reported at least once as having been found in the dust on the walls of a sick-room.* It is, however, a common inhabitant of the healthy mucous membrane of man.

In 1880 Pasteur produced septicemia in rabbits by inoculation with normal human saliva. The microbe found by him in this form of "sputum septicemia" (microbe septicémique du salive) was doubtless Streptococcus pneumoniæ. Sternberg and many others have also found this germ in saliva. Park and Williams † in New York succeeded in isolating typical pneumococci from the mouth, nose, and throat secretions of a large percentage of healthy individuals (forty out of eighty). The cocci are found in individuals living in both city and country and in those of both indoor and outdoor occupation. Those present in healthy individuals are more likely to be atypical than those found in pneumonia, and, judging from animal experiments, are, as a rule, less virulent.

Pathogenicity for Man.—The well-nigh universal occurrence of the pneumococcus in the tissue of inflamed lungs in cases of lobar pneumonia, especially in those parts where the pathologic changes are most active, and also its regular appearance in the sputum of the majority of pneumonia patients, afford strong arguments for connecting this organism causally with lobar pneumonia. The same is true of many cases of lobular pneumonia. Still more convincing is the fact that the pneumococcus is present in the circulating blood in practically all cases of lobar pneumonia. It was at one time supposed that the finding of the pneumococcus in the blood was of ominous significance and pointed to a fatal termination, but as a result of the more recent researches, this view is no longer tenable. The invasion of the blood is looked upon at present as a constant

* Netter: Compt. Rend. de la soc. biol., 1897, 49, p. 538.

† Park and Williams: Jour. Exp. Med., 1906, 7, p. 403.

accompaniment of infection. Rosenow * found pneumococci in the blood in one hundred and thirty-two out of one hundred and forty-five cases.

It is sometimes held that lobar pneumonia is caused by bacteria that are inhaled and make their way directly to the alveoli of the lungs (Weichselbaum †). Lobular pneumonia, on the other hand, is supposed to be due to the aspiration of bacteria that are present in the bronchial exudate, or it may arise from a general extension of a bronchitis into the alveoli. The type of pneumonia produced by such organisms as B. influenzæ and B. diphtheriæ is usually of the latter variety (bronchopneumonia). Since these bacteria are probably present in the first instance in the exudate of the upper respiratory passages, the bronchopneumonia may be looked upon as more or less direct extension of the initial infection. A far greater variety of microbes is found associated with lobular pneumonia than with lobar, both as the primary exciting agents and as participants in mixed infections. Probably over 95 per cent. of all cases of pronounced lobar pneumonia are due to the pneumococcus. The so-called atypical cases of lobar pneumonia are also due, in the great majority of cases at any rate, to the pneumococcus, and there is no reason for assuming that a case presenting anomalous symptoms is caused by an unusual bacterial species. The differences observed in pneumococcus infections are related to the susceptibility of the affected individual, and perhaps in some degree to the virulence of the infecting micro-organism. In lobular pneumonia, and more rarely in lobar pneumonia, mixed infections may occur, the pyogenic micrococci being the accessory organisms most commonly found. As already pointed out, both streptococci and staphylococci are capable by themselves of provoking pneumonic processes of the lobular type, and when they are found with the pneumococcus they may be regarded as taking some part in producing the observed pathogenic effects. How great an influence is exerted by such mixed infections upon the outcome of a case is still uncertain. The question as to how far the anatomic and clinical character of a pneumonia is affected by the nature of the microbe or microbes concerned is also unsettled. It has not been shown that the lobular pneumonia produced by

* Rosenow: Jour. Infect. Dis., 1904, 1, p. 280.

† Weichselbaum: Kolle and Wassermann, Handbuch, 3, p. 240.

Streptococcus pneumoniæ is materially different from the type of pneumonia, for example, occasionally produced by the typhoid bacillus.

The pneumococcus must be held responsible not only for the causation of most cases of both lobar and lobular pneumonia, but for a number of other pathologic processes and conditions. Among the most common of these are inflammations of the pleura, pericardium, endocardium, and meninges. These may occur either as independent and primary affections or as complications and sequels of pneumonia. Inflammations of the meninges, and particularly of the middle ear, are rather frequently secondary to pneumonia, and are also sometimes primary. The connection between inflammation of the middle ear and meningeal infection has been often noted. There can be no doubt that the pneumococcus on its road to the cerebrospinal membranes travels occasionally by way of the nasal passages, but the pneumococcus is frequently found in the blood, and other modes of access are also possible.

To these inflammatory conditions of pneumococcal origin might be added a long list of others provoked by the same organism. There appear to be few, if any, organs or tissues that are not under some circumstances subject to attack. Enteritis, conjunctivitis, and a great variety of other affections are occasionally due to the activity of the pneumococcus. In general, pneumococcus infections tend to a more favorable outcome than similar infections with streptococci or staphylococci, but the statement admits of exceptions.

In the production of pneumonia an important part is played by causes affecting individual predisposition. The well-known age-fatality of the disease which bears most heavily upon infants and upon the aged demonstrates the influence of bodily conditions in determining the course of infection. Disturbances of the circulation due to severe or sudden exposure to cold is another familiar factor of causation. The influence of alcoholism as a predisposing factor is especially marked. A variety of other causes, such as infection with a disease like measles or typhoid fever, can lead to a lessening of the normal resistance, so that pneumococci which are taken in with the inspired air, or are perhaps always present in some part of the respiratory tract, can penetrate the alveoli of the lungs and excite the pneumonic process. In most, if not all, of the

infectious diseases the influence of predisposing factors is important; in pneumonia it is of almost supreme significance.

At the same time the possibility of the transmission of infection, particularly in the case of very virulent strains, must always be kept in mind. It has already been pointed out that pneumococci can retain their vitality in fine spray and in dust for a short time and in dried sputum for a considerably longer period, extending even over some weeks. As in many other bacterial diseases, so also in pneumonia, convalescents and persons coming in contact with patients or convalescents may carry virulent germs in their respiratory tract for weeks or months. Sometimes an apparently simple "cold in the head" may be due to the pneumococcus. Many cases are on record of apparently rather direct communication of pneumonia from one person to another, but few such cases have been studied with adequate bacteriologic methods. It is plain, however, pending determination of the degree of danger, that disinfection of sputum should be rigorously practised, and that the proximity of a pneumonic patient should not be courted, especially by the enfeebled or those in a condition inviting infection.

Pathogenicity for the Lower Animals.—Animal inoculation has thrown a flood of light upon the nature and course of pneumococcus infection in man. The injection of human saliva into rabbits by Pasteur gave rise to a rapidly fatal generalized infection. The "sputum septicemia" caused by this procedure is now known to be due to the pneumococcus; precisely similar results today follow the injection of pure cultures of this organism. Mice, like rabbits, exhibit a high susceptibility to pneumococcus infection; guinea-pigs are less sensitive. It is a noteworthy fact that in these animals lung lesions, when they occur at all, are slight and usually limited to the bronchopneumonic type. The experiments with the pneumococcus present an example of the general law that susceptibility is characterized by general septicemic infection, resistance by the occurrence of a localized process. Resistant animals, such as the dog, show an approximation toward the type of pneumococcus infection observed in man. It is possible to produce typical lobar pneumonia in the rabbit by carefully balancing the susceptibility of the animal and the virulence of the germ. This may be effected either by employing attenuated cultures of the pneumococcus (injected

intratracheally, intravenously, or intraperitoneally), or by partially immunizing the animals so that they acquire sufficient resistance to prevent a general infection.*

On the basis of these experiments the course of pneumococcus infection in man may be more readily comprehended. Man must be regarded as an animal of rather high normal resistance. This relative immunity may, however, be so far reduced as to permit of the production of localized manifestations, which in still more susceptible individuals may lead on to a fatal septicemia. In some cases death is due to overwhelming interference with respiration caused by the local pulmonary lesions; in others, to general systemic poisoning or toxemia.

Virulence and Toxin Production; Agglutination.—The occurrence of cases of pneumonia differing widely in severity has been supposed to indicate the existence of strains of pneumococci of varying degrees of virulence, although in any given instance it is plainly impossible to apportion the relative influences of individual susceptibility and of bacterial virulence. The occasional appearance of epidemics of pneumonia of a highly virulent character has also been conjectured to be due to the presence of strains of unusual pathogenic power. These inferences are supported to some extent by the experimental evidence, which shows that considerable fluctuations in virulence occur in cultures. The virulence of a given strain may be greatly exalted by animal passage. This fact has been adduced to explain the virulence of the epidemic type of pneumonia, it being supposed that pathogenicity is heightened by frequent transfer from person to person. Attenuation of pneumococci may also be effected experimentally in various ways, such as growth at a temperature above 39° C. or in a medium in which abundant acid production occurs (milk); in the ordinary culture-media a spontaneous diminution of virulence takes place.

Many attempts have been made to obtain a specific soluble toxin from cultures of the pneumococcus, but so far they have signally failed. Macfadyen† succeeded in preparing a powerful thermolabile poison by the freezing-and-grinding method, but there is no evidence that this substance is the same as that to which the

* Wadsworth: Amer. Jour. Med. Sci., 1904, 127, p. 851.

† Centralbl. f. Bakt., 1906, 43, p. 30.

pneumococcus owes its pathogenicity for man. The poisonous bodies by which this micro-organism produces its specific effect are perhaps generated only under the conditions prevailing within the living body of its host, or are perhaps so firmly bound to the bacterial cell substance that they are not separated from it by the methods that have so far been applied.

Rosenow* has made the interesting observation that, "Extraction or autolysis of virulent pneumococci in NaCl solution brings into the solution a substance or group of substances which inhibits the action of pneumococco-opsonin; avirulent pneumococci take up this substance and now become not only resistant to phagocytosis, but exhibit also to some degree the property of animal virulence; after extraction of the substance virulent pneumococci acquire the power to absorb pneumococco-opsonin."

Agglutination of pneumococci by the blood-serum of pneumonia patients has been demonstrated by a number of observers.† The clumping is accompanied by noticeable changes in the capsular and cell-substance, which have impressed some observers as indications of a lytic or degenerative process. It has been shown, however, that although the cocci are profoundly affected morphologically by the agglutinating serum, they retain their vitality for a long time (twenty-five days, Rosenow) and even their virulence. The degree of agglutination produced by the serum of pneumonia patients is at best feeble. The highest dilutions at which agglutination is obtained are not, as a rule, over 1 : 40 or 1 : 50. The agglutinative property of the blood is most marked about the time of the crisis, and then gradually diminishes.

Immunity and Serum-therapy.—An attack of pneumonia in man is probably followed by some increase in resisting power, but such acquired immunity is far from permanent. One attack may succeed another after a short interval; in some cases predisposition to a fresh attack seems to be increased. Susceptible animals (rabbits) may be rendered immune by inoculation with dead or attenuated pneumococci, followed by inoculation with virulent cultures. The degree of resistance obtained is often considerable.

* Rosenow: Jour. Infect. Dis., 1907, 4, p. 285.

† Besançon and Griffon, Neufeld, Wadsworth: Jour. Med. Res., 1903, 10, p. 228; Rosenow: Jour. Infect. Dis., 1904, 1, p. 280.

It is not certainly known upon what this resistance depends. On the basis of animal experiments some observers (*e. g.*, Wassermann *) concluded that immunity was due to the production of a bactericidal substance. Later experiments, however, have shown that pneumococci develop in normal and in pneumococcic human serum with equal rapidity. In fact, neither a bactericidal nor an antitoxic property has been shown to exist in immune serum. Rosenow † has found that non-virulent pneumococci are susceptible to phagocytosis, while virulent strains are not. The extent to which phagocytosis is important in bringing about the crisis and healing of pneumonia is still undetermined. Attempts to employ therapeutically the serum of immunized animals have so far been eminently unsuccessful. Neither a theoretical nor a practical basis for serum-therapy in pneumonia has yet been reached.

* Wassermann: Deut. med. Wchschr., 1899, 25, p. 141.

† Rosenow: Jour. Infect. Dis., 1906, 3, p. 683.

CHAPTER XII

THE MENINGOCOCCUS (MICROCOCCUS MENINGITIDIS)

Inflammation of the meninges or investing membranes (pia-arachnoid) of the brain and spinal cord may be provoked by a variety of organisms, and may occur either as a primary affection or secondarily in the train of an infection originally begun elsewhere. One form of meningitis, characterized especially by epidemic spread and usually designated as *epidemic cerebrospinal meningitis*, is accompanied by the presence of a specific micro-organism, commonly known as the meningococcus.

This organism, to which the name Micrococcus meningitidis or M. intracellularis has been given, appears to have been seen by Leichtenstern in the meningeal exudate as early as 1885. The first important work upon it, however, was that of Weichselbaum,* who in 1887 described it in detail as the characteristic micrococcus found in six cases of acute cerebrospinal meningitis. Weichselbaum also carried out successful animal experiments. Some years later the conclusions arrived at by Jäger † in connection with an outbreak of epidemic meningitis in the military garrison at Stuttgart, although based to some extent on faulty observations, corroborated Weichselbaum's results in their essential features, and were the cause of renewed interest in this subject. The etiologic rôle of the meningococcus has since been securely established by a number of investigations, among which may be mentioned especially the extended researches of Councilman, Mallory and Wright.‡

Morphology.—In cover-slip preparations of the meningeal exudate the meningococcus appears in diplococcus or in tetrad form (Figs. 42 and 43). The micro-organism occurs characteristically in the interior of the polymorphonuclear leukocytes, these cells being sometimes so packed with diplococci that the nucleus

* Weichselbaum: Fortschr. d. Med., 1887, 5, p. 573.

† Jäger: Ztschr. f. Hyg., 1895, 19, p. 351.

‡ Special Report of the State Board of Health of Massachusetts, 1898.

is obscured. When tested by Gram's method of staining, decolorizing takes place. In cultures the meningococcus is about 1 μ in diameter, and appears, as a rule, in pairs; short chains are seen more rarely. No capsule is present, although irregularities in staining, and the occurrence of swollen cells have led to some confusion on this point. Involution forms are common.

Cultural Characters.—In artificial media the growth of the meningococcus at best is scanty. Great difficulty is sometimes experienced in obtaining cultures of the organism from pathologic exudations. Upon ordinary agar and in broth the growth is feeble; on potato, as a rule, no visible growth occurs, although rarely a delicate yellow-brown coating is formed; no change is produced in litmus-milk. A more satisfactory growth is obtained by the use of a glycerin-agar or of a blood-serum mixture. Upon Löffler's medium in twenty-four hours at 37° white, shining, viscid colonies are formed which tend to coalesce; the blood-serum is not liquefied. According to Flexner,* the use of sheep serum is advantageous. Sheep-serum-water prepared by Hiss' method† is mixed in a proportion of about 1 : 10 with sterile nutrient glucose-agar; this medium has proved especially favorable for the growth of the meningococcus.

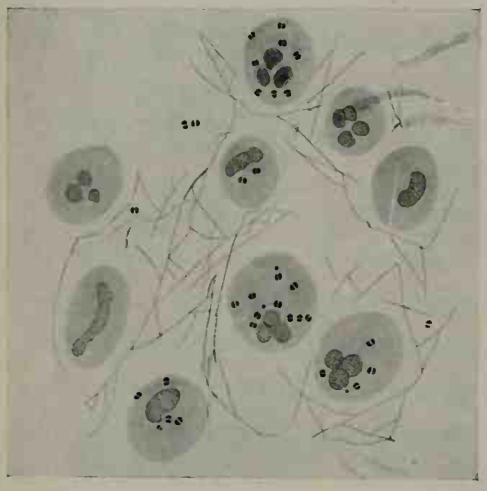


Fig. 42.—Meningococcus in pus cells (Councilman): Pus cells containing diplococci from the meninges. A few diplococci are in the exudate outside of the pus cells. Between the pus cells there are delicate fibrillæ of fibrin. The illustration is an accurate representation of a group of cells in the field of the microscope.

Whatever method of isolation be employed, it is necessary to deal as expeditiously as possible with exudations or secretions containing meningococci, since the organisms soon perish once the exudations are removed from the body. Very slight resistance is shown to desiccation. The life of artificial cultures of the menin-

* Flexner: Jour. Exp. Med., 1907, 9, p. 105.

† Sheep serum one part, distilled water two parts, inulin 0.1 per cent.

gococcus is usually brief; in cultures that are two or three days old the cells give evidence of marked degeneration. Flexner has shown that the organism contains an intracellular enzyme capable of destroying its own cell-substance. Vitality can be preserved in ordinary cultures only by frequent transfers. The addition of calcium carbonate to sheep-serum-water agar, however, enables the meningococcus to survive for some time.

Pathogenicity for Man.—Many cases of meningitis due to the meningococcus are characterized by special features which distin-

Fig. 43.—Meningococci in pus from brain abscess (Flexner).

guish them from cases of meningitis produced by other organisms, as, for example, from pneumococcal meningitis. The most marked lesions occur at the base of the brain, extending from the optic commissure backward over the crura, pons, and medulla. The meninges of the entire brain are rarely affected. The cord is always affected, and to a greater extent than in any of the other forms of meningitis. The usual history is that of sudden onset, and many so-called fulminating cases occur. The disease is most frequent in children and young adults, cases being rare in persons over thirty-five years of age. In the epidemic studied by Councilman, Mallory, and

Wright, the mortality was 76 in 111 cases (68 per cent.); in New York city in 1905, out of 2755 cases reported, there were 2026 deaths (73 per cent.). While the mortality is thus usually high, epidemic meningitis stands in contrast to the practically invariably fatal meningitis caused by other bacteria.

During life the surest method of diagnosis of this form of meningeal disease is the detection of the specific micro-organism in spinal fluids obtained by means of lumbar puncture. Especially prominent among the symptoms are the involvement of the eye and ear, the infection showing a definite tendency to extend along the optic, auditory, and fifth nerves. The meningococcus is sometimes found in the circulating blood. A general infection with the meningococcus seems to be always secondary to disease of the meninges.* Under some circumstances it can give rise to a focal pneumonia, which differs from that produced by the pneumococcus. Complications in general are not very frequent, acute rhinitis being the one most commonly reported. It is still an open question whether the nasal cavity is the usual portal of entry for this organism, and the meningitis is secondary to an acute rhinitis, or whether the rhinitis is secondary to a blood infection. In the first days of the disease the meningococcus can be demonstrated in the nasal secretions in a large proportion of cases. Exceptionally the meningococcus may live as a saprophyte on the nasal mucous membrane of certain healthy individuals, especially such as have been in contact with infected persons. The remarkably slight resistance of the coccus to drying favors the assumption that the disease is usually spread by germ-carriers, whether convalescents, actual patients, or healthy persons. Direct contact with infected material smeared upon handkerchiefs, towels, or drinking-cups, and inhalation of infectious droplets, are in all probability the means by which infection is spread.

Pathogenicity for Other Animals.—Rabbits and adult guinea-pigs display little susceptibility to inoculation. White mice are somewhat more susceptible, especially to intraperitoneal inoculation. Young guinea-pigs (175 to 200 grams) are quite highly susceptible to intraperitoneal inoculation, but in order to produce a fatal result rather large amounts of culture must be used, and, as

* See Duval: Jour. Med. Res., 1908, 19, p. 259.

a rule, the meningococcus fails to invade the tissues. The guinea-pig experiments indicate that the death of these animals is caused by a poison liberated by the disintegration of the bacterial cells. Cultures killed by heat, and cultures subjected to autolysis are quite toxic. Councilman and his co-workers * produced typical meningitis in a goat by intraspinal injection of pure cultures. Flexner † has reproduced in monkeys the lesions and to some extent the symptoms of acute meningitis as they occur in man.

Agglutination and Immunity; Curative Antiserum.—Agglutinins are produced by animal inoculation with the meningococcus, and appear also in the blood of patients suffering from epidemic meningitis; the serum of the latter agglutinates the specific cocci in a dilution of 1:50 or higher. Kolle and Wassermann ‡ have shown that when large quantities of meningococci are injected into the body of a horse, agglutinins, opsonins and also specific immune bodies (amboceptors), are produced, and that the horse-serum has a curative effect; and Flexner § has likewise found that guinea-pigs and monkeys can be saved from otherwise fatal meningococcus infection by a specific antiserum. A curative serum has recently been prepared by Flexner and Jobling ‖ by injecting a horse first with gradually increasing doses of dead meningococci, then of living cocci, and finally of an autolysate. The injection of the anti-meningitis serum directly into the spinal canal in human cases has a marked influence upon the course of the disease. The effect is due, according to Flexner and Jobling, partly to an antitoxic action, partly to the stimulus that the serum gives to increased phagocytic digestion, and partly to its direct injurious action upon the cocci. Of 712 cases of epidemic meningitis treated with the Flexner-Jobling serum, 488 recovered and 224 died. In the Children's Hospital, Boston, the mortality from this disease between 1899 and 1907 varied from 60 to 80 per cent. After Nov. 1, 1907, the serum was employed, and since its introduction the mortality has never gone above 25 per cent.¶

* Special Report Mass. State Board of Health, 1898, p. 77.

† Flexner: Jour. Exp. Med., 1907, 9, p. 142.

‡ Kolle and Wassermann: Deut. med. Wochenschr., 1906, 32, p. 609.

§ Flexner: Loc. cit., p. 168.

‖ Flexner and Jobling: Ibid., 1908, 10, p. 141.

¶ Jour. Amer. Med. Assoc., 1909, 53, p. 1443.

CHAPTER XIII

THE GONOCOCCUS (MICROCOCCUS GONORRHŒÆ); OTHER PATHOGENIC MICROCOCCI

Few diseases are so widely disseminated through all classes of society as gonorrhea. The conservative statistics of Erb,* based on the history of about two thousand male patients, mostly among the German middle classes, showed that about 48.5 per cent. had had gonorrhea. Some German authorities would place the proportion in the whole population at a much higher figure.

Neisser † in 1879 first called attention to the constant presence of a peculiar coccus in gonorrheal pus. In cases of gonorrhea of recent origin this was the sole organism found; it occurred not only in the urethral and vaginal discharges of ordinary gonorrhea, but was present in the exudations of conjunctivitis due to gonorrheal infection. Pure cultures of this organism were first obtained by Bumm‡ (1885), who also succeeded by inoculation experiments in demonstrating beyond doubt its casual relation to gonorrhea.

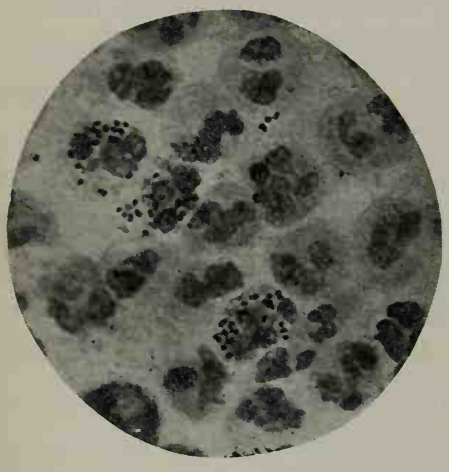


Fig. 44.—Smear from gonorrheal pus. Romanowsky; × 1100 (Hicks).

Morphologic and Cultural Characters.—Morphologically the gonococcus (Micrococcus gonorrhœæ) is very similar to the meningococcus. In preparations made from gonorrheal pus the cells occur in pairs, with the flattened sides in juxtaposition; the appearance in stained preparations is like that of a coffee-bean. In pure cultures the cocci are often aggre-

* Erb: Münch. med. Wchnschr., 1906, 53, p. 2329.

† Neisser: Centralbl. f. d. med. Wissensch., 1879, 17, p. 497.

‡ Bumm: "Der Mikroorganismus der gonorrhoischen Schleimhauterkrankungen," Wiesbaden, 1885.

gated in irregular masses, but, especially in young cultures, also show the characteristic diplococcus arrangement. Like the meningococcus, *it is found within the pus cells*, sometimes in enormous numbers (Fig. 44). In the earliest stages of infection, however, gonococci are found free in the serum, and the same is true of cases of gonorrhea of long standing.

The cocci in the pus cells do not invade the nucleus, but are confined to the cytoplasm of the cell. There is satisfactory evidence that the gonococci are picked up by the phagocytes and do not actively penetrate the latter; they are, indeed, entirely non-motile. The gonococci found inside the leukocytes are but slightly altered in appearance, and in many cases are still alive; no multiplication, however, has been demonstrated, although it is possible that this occurs. Whether the extensive phagocytosis that takes place has any influence upon the course of gonorrhea is unknown. *When treated by Gram's method, the gonococcus completely loses the stain.** Its behavior toward the Gram stain, together with its coffee-bean form and intracellular situation, usually serves to distinguish the gonococcus from related organisms, such as the common pyogenic cocci found in the urethral or vulvovaginal tracts. From the meningococcus, however, the gonococcus is differentiated principally by the fact that it does not usually grow on the ordinary culture-media. Some strains, however, are said to grow on glucose or glycerin-agar from the start, but, as a rule, less luxuriantly than the meningococcus. In practice little confusion is caused by the close resemblance of these two organisms, since they are not liable to occur in the same tissues. Meningitis is, however, in rare instances, caused by the gonococcus. Organisms other than the gonococcus, staining like it and contained in the polymorphonuclear leukocytes, are occasionally, although rarely, found in the urethral and vaginal secretions.

No growth generally takes place upon the ordinary gelatin and agar culture-media unless considerable quantities of pus are smeared on the surface. Bumm was the first to succeed in cultivating the gonococcus, accomplishing this by use of a mixture of ox, sheep

* The gonococcus is decolorized rather slowly. In testing for this organism the film should be exposed for ten minutes instead of five, to the action of alcohol.

and human serum. Later (1891) Wertheim * devised a medium which has proved highly serviceable, and is today, with certain modifications, in general use. The most successful results in every way are obtained when blood or blood-serum is added to the usual nutrient media.

Wertheim's serum-agar is prepared by adding one part of human serum (or other serous fluid, such as ascitic or hydrocele fluid) to from two to three parts of nutrient agar. The serum is first warmed to 40° C., and then added to liquid agar of the same temperature. After a number of generations upon Wertheim's medium a scanty growth may occur on ordinary agar unmixed with serum. Nutrient agar smeared with sterile human blood is also an excellent medium for the gonococcus. Upon Wertheim's serum-agar the colonies formed by the gonococcus resemble those of streptococcus, but are in general somewhat larger, less translucent, and of a more tenacious consistency. In ascitic broth (three parts meat broth to one of ascitic fluid) a finely granular growth occurs on the walls and bottom of the test-tube. Toward external influences the gonococcus displays a high degree of sensitiveness. According to most experimenters, cultures are injuriously affected by a temperature of 40° to 41° C. The gonococcus is sensitive to drying, and under ordinary conditions can survive exposure to the air for only a very short time, although in masses of dried pus it may live exceptionally for six or seven weeks. In favorable culture-media it rarely maintains its vitality more than forty-eight to seventy-two hours at room temperature, but, like many other bacteria, will live longer if kept in a refrigerator.

Correct diagnosis of gonococcus infection, based on the discovery of Gram-negative diplococci within pus-cells, is frequently a relatively simple matter, but it must be remembered that there are several sources of error. As already pointed out, gonococci sometimes lie free in the serum and are not contained within the leukocytes. Again, as already mentioned, the occasional presence of organisms similar to the gonococcus, especially in the vulvovaginal tract, makes it advisable in doubtful cases to fall back on cultural methods. If microscopic findings are negative, a much higher degree of certainty can be obtained by suitable cultural methods

* Wertheim: Deut. med. Wchnschr., 1891, 17, p. 1351.

in the hands of an experienced observer. Centrifugalization of the urine is often resorted to, and increases the chances of finding gonococci in the sediment either microscopically or culturally.

Inoculation Experiments.—The lower animals (including apes) are not susceptible to inoculation either with pure cultures of the gonococcus or with gonorrheal pus. Whether introduced into the peritoneum or the urethra or applied to the conjunctiva of these animals, the gonococci have shown themselves impotent to effect an invasion of the tissues. The poisonous products contained in cultures have, however, some effect upon animals, and will cause the death of guinea-pigs and white mice. These poisonous substances are not true toxins and are not diffused into the surrounding media during the life of the cell, but, according to the statement of most investigators, are constituents of the bacterial cell-body. On the death of the cell they may appear as disintegration products in the surrounding fluid. They are quite resistant to heat, and are able, according to some investigators, to withstand a temperature of 80° C. or even 115° C. De Christmas* and his co-workers have reported successful immunization experiments with these toxic substances, but their results have not been corroborated by other experimenters. Inoculation of the human subject (both sexes) with pure cultures of the gonococcus gives rise to a typical infection (Bumm, 1885). The mucous surfaces seem to be especially susceptible, and inoculation of the urethra almost invariably succeeds. Repeated demonstration of the specificity of this organism for gonorrhea has thus been obtained. The poisonous bodies above mentioned will evoke suppuration when injected into the urethra, but since the products of other microbes, as, for example, staphylococci and colon bacilli, produce the same result, the effect cannot be regarded as specific. Little if any immunity is conferred by an infection, reinoculation being successful at short intervals; clinically it is observed that an acute attack may be superimposed upon a chronic gonorrhea. An antibody (amboceptor) has, however, been found in the blood of gonorrheal patients.† Torrey ‡ and others have observed that agglutinins and precipitins are produced in rabbits

* De Christmas: Ann. de l'Inst. Past., 1900, 14, p. 331.

† Bruck: Deut. med. Wchnschr., 1906, 70, p. 36.

‡ Torrey: Jour. Med. Res., 1907, 16, p. 329.

and other laboratory animals inoculated with cultures of gonococci. The close relationship of the gonococcus to the meningococcus is shown with especial clearness in the observation of Martha Wollstein * that the agglutinins, the protective power, and the amboceptors developed in the serum of immunized animals seem to be largely common to both micro-organisms.

Results of Gonococcus Infection.—As a rule, the gonococcus attacks primarily the human urethra, and then gives rise to an inflammation which may be followed by chronic urethritis and stricture. The dangerous extragenital complications and sequelæ of this affection are not so generally known as they should be. So far from being a localized inflammation confined to the immediate neighborhood of the original point of infection, the gonorrheal process may be far-reaching in its effects. In the female particularly, the entire genito-urinary tract may be involved, the Fallopian tubes, the ovaries and the peritoneum being invaded not at all uncommonly. Spread of the infection along contiguous mucous surfaces may likewise occur in the male, causing epididymitis and other inflammatory conditions. The gonorrheal ophthalmia of the new-born due to infection at birth is a well-known consequence of maternal infection. Although exact information is not obtainable, it is estimated that 10 per cent. of all cases of blindness are traceable to this source, and that in the United States there are at least 12,000 children blind from this cause.

The gonococcus may also invade the blood from local lesions and be carried by the lymph and blood-streams to distant parts of the body. In this way it can incite a variety of extragenital lesions, some of which result fatally. Especial predilection is shown for the synovial membranes of the joints, where it causes the so-called gonorrheal rheumatism, and for the heart-valves, where it produces endocarditis. It is possible to obtain the gonococcus in pure culture from the affected region in a considerable proportion of cases. According to the statistics of Neisser,† gonorrheal metastases occur in about 0.7 per cent. of all cases of gonorrhea coming to the knowledge of physicians. Local or general complications, however, occur in about 30 per cent. of all cases. Meta-

* Wollstein, Martha: Jour. Exp. Med., 1907, 9, p. 588.

† Neisser: Kolle and Wassermann, Handbuch, 3, p. 182.

static conjunctivitis without direct inoculation of the conjunctiva has been reported. It is uncertain whether this is always due to the presence of gonococci carried to the conjunctival sac in the body-fluids or whether circulating toxic substances act on the cellular elements of the conjunctiva.

A peculiarly dangerous feature of gonococcus infection is the long period during which an infected man or woman may be capable of infecting others. Gonococci may persist in the genito-urinary secretions for years after apparently complete recovery has taken place. By this means serious inflammations of the genital tract are produced in thousands of innocent wives by their previously infected husbands.

Epidemics of gonorrheal vulvovaginitis in little girls due to carelessness in the use of towels, wash-cloths, thermometers and bath-tubs are not uncommon, and are a serious problem in many institutions. Infection may be followed by the same grave consequences to the female reproductive organs as gonococcus infection produced in any other manner.

Gonococcus Vaccine.—Cole and Meakins * have employed Wright's method of subcutaneous vaccination in the treatment of gonorrheal arthritis. An emulsion of gonococci in 0.85 per cent. salt solution heated for one hour at 65° is first injected, the initial dose containing usually about 300 million dead gonococci. The succeeding vaccinations are gradually increased in amount until 1000 to 1200 million gonococci are administered in a single dose. The results obtained by Cole and Meakins were often favorable, and were more marked in the chronic cases than in the acute ones. While the authors express skepticism as to the value of the opsonic index as a guide to the administration of vaccine, and "do not feel that the danger of cumulative negative phases is a real one," they conclude as follows: "In no case have we seen the administration of gonococcus vaccine do harm, and we feel that these cases offer sufficient justification for the treatment of gonorrheal arthritis by means of vaccines in doses of 500 to 1000 million, administered every seven to ten days." Irons, † studying a larger series of cases, has also obtained results indicating that in certain

* Cole and Meakins: Johns Hopkins Hosp. Bull., 1907, 18, p. 223.

† Irons: Jour. Infect. Dis., 1908, 5, p. 279.

cases of gonococcus arthritis recovery can be hastened by the injection of dead gonococci.

OTHER PATHOGENIC MICROCOCCI

Micrococcus Melitensis.—In 1887 Bruce,* while investigating a disease known as Malta fever, or Mediterranean fever, discovered a micro-organism in the spleen which has since been proved to stand in causal relation to the affection. Malta fever is particularly common on the island of Malta, but occurs also on other islands and on the shores of the Mediterranean, and has also been occasionally reported from India, South Africa,the Philippines, and the West Indies. Several cases have come under observation in the United States, for the most part among persons recently returned from the Philippines.

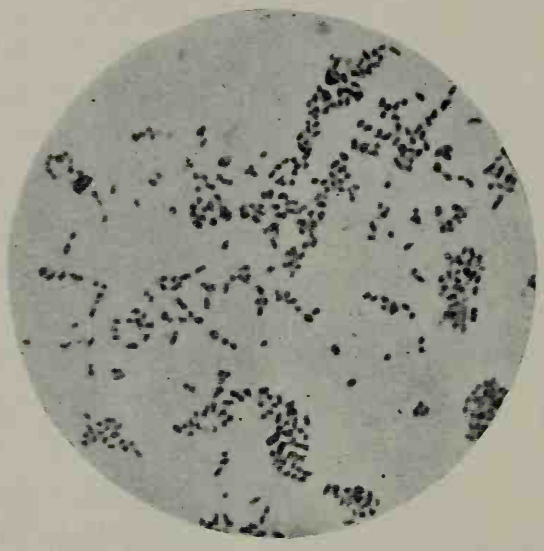


Fig. 45.—Micrococcus melitensis. Carbol fuchsin; × 1200.

M. melitensis is a very small coccus, about 0.5 μ or less in diameter, usually occurring singly or in pairs, though in cultures short chains are found (Fig. 45). A bacillary form occurs in cultures grown at 20° C. Unlike the ordinary streptococcus, it loses the stain by Gram's method, does not ferment glucose, and renders milk slowly alkaline. On the ordinary culture-media it grows slowly without presenting especially characteristic features. Gelatin is not liquefied. In broth cultures there is no odor, and indol is not produced. Agar-plate colonies are small and transparent. A moist, transparent growth is formed on potato.

Malta fever, as it affects man, is a disease of long duration

* Bruce: Practitioner, 1887, 39, p. 161.

and extremely irregular and undulating course, marked by shifting articular rheumatism and frequent and profuse sweatings. The case mortality is low (2 to 3 per cent.). The surest means of diagnosis is the agglutination test. Bassett-Smith is of opinion that a positive agglutination with a 1:30 dilution may be considered conclusive evidence of Mediterranean fever past or present.* Agglutination may occur with serum diluted as much as 1:6000. In a large proportion of cases (82 per cent.) M. melitensis has been found in the peripheral blood. It can usually be obtained from the spleen at death or by spleen puncture during life. Like the typhoid bacillus, M. melitensis is contained in the urine of many patients. It is less commonly found in the feces and in milk. There is no doubt that M. melitensis is the cause of Malta fever, since several laboratory accidents have led to the infection, through small wounds, of persons working with pure cultures.† Monkeys, goats, and probably cows may be infected by injection and by feeding; the disease occurs spontaneously in goats and cows, and the urine and milk of these animals often contain the specific germ.

The mode of infection in Malta fever was for a long time quite obscure. The discovery that goat's milk often contains the specific micrococcus in large numbers at length gave the clue. It is stated that about half the goats in Malta are infected with Mediterranean fever, and that one-tenth are constantly passing the parasite of this disease in their milk. Incidents like the following emphasize especially this source of infection. Sixty-five goats, all apparently healthy, were shipped at Malta in 1905 on the steamship "Joshua Nicholson" for export to America. The goats' milk was drunk during the passage in large quantities by the captain and many of the crew, with the result that almost every one who drank the milk was struck down with Malta fever. Sixty of the goats (five having died) on arrival in America were examined and thirty-two found to give the agglutination reaction, while M. melitensis itself was isolated from the milk of several of them.‡ As a result of preventive measures directed against the use of goats' milk in Malta

* Bassett-Smith: Brit. Med. Jour., 1902, 2, p. 861.

† Reports of the Commission on Mediterranean Fever, London, 1906, Part 4, p. 104.

‡ Report of the Commission on Mediterranean Fever, Part 6, 1907, p. 70.

the cases on that island in the latter half of 1906 dropped to one-tenth of what, judging from past experience, would have been their normal number.

It seems possible that dust, contact and, rarely, inoculation through the agency of biting or suctorial insects, may play some part in spreading infection, but many observers believe that the cases arising from all these causes combined are relatively very few in number. Sergent,* however, while admitting the predominance of milk infection, emphasizes the possibilities of infection by contact. Water is apparently not a vehicle of transmission.†

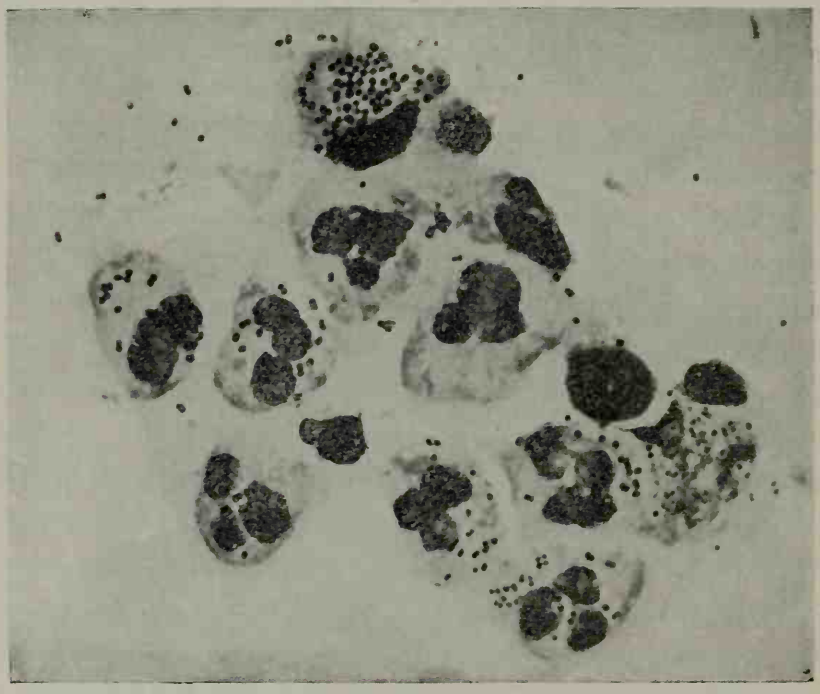


Fig. 46.—Micrococcus catarrhalis in smear from sputum (F. T. Lord).

Micrococcus catarrhalis.—This organism has been found by Seifert,‡ Kirchner,§ Pfeiffer, and others in the sputum and tissues of a number of cases of bronchitis, pneumonia, whooping-cough,

* Sergent: Ann. de l'Inst. Past., 1908, 22, p. 225.

† The bacteriology and epidemiology of this disease are very fully discussed in the Reports of the Commission Appointed by the Admiralty, the War Office, and the Civil Government of Malta for the Investigation of Mediterranean Fever, under the Supervision of an Advisory Committee of the Royal Society, Parts I.—VII. London, Harrison and Son, 1905–07.

‡ Seifert: Volkmann's Samm. klin. Vortr., No. 240.

§ Kirchner: Zeitsch, f. Hyg., 1890, 9, p. 528.

and other affections in which the respiratory tract is involved. It has often been reported in association with the influenza bacillus. Its etiologic relations are not altogether clear. Morphologically it resembles the meningococcus; it loses the stain, however, when treated by Gram's method. Growth occurs upon the ordinary nutrient media; blood-agar is said to be especially favorable. The pathogenicity of M. catarrhalis for the laboratory animals is slight. Owing to the relatively frequent occurrence of this organism in the upper respiratory tract, care must be taken to avoid confounding it with the meningococcus. The fact that it grows well on the ordinary nutrient media even in the first generation serves to mark it off from the latter organism. M. catarrhalis has been found a number of times in "epidemics simulating influenza." Similar organisms have been found in multiple abscesses (Wells *) and infectious dermatitis (Lyon and Wherry†).

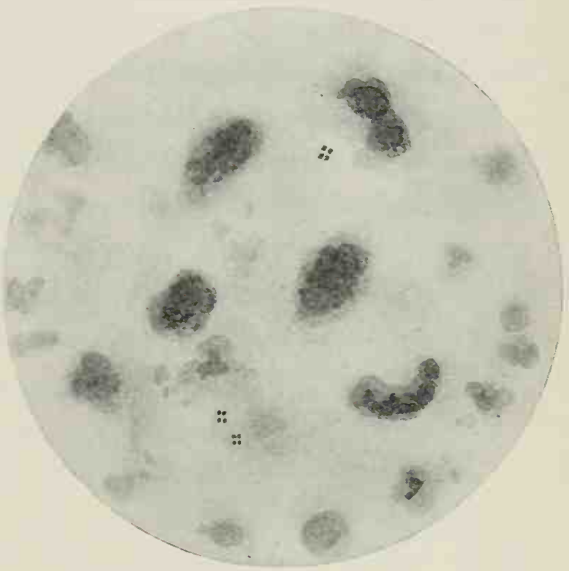


Fig. 47.—Micrococcus tetragenus from peritoneal pus (Bythell).

Micrococcus zymogenes.—MacCallum and Hastings‡ observed this microbe in a case of acute endocarditis, and it has since been found in localized pathologic processes in several cases.§ Morphologically it is a small micrococcus, occurring most frequently in pairs, sometimes in short chains. It gives a rather profuse, thin growth on agar, produces acid in glucose and lactose broth, liquefies gelatin slowly, and forms minute colonies on potato. Its behavior in milk is especially characteristic, abundant acid being produced, accompanied by the formation of

* Wells: (Not published.)

† Lyon and Wherry: Amer. Med., 1903, 6, p. 401.

‡ MacCallum and Hastings: Jour. Exp. Med., 1899, 4, p. 521.

§ Harris and Longcope: Centralbl. f. Bakt., 1901, 30, p. 353.

a curd which is slowly dissolved. It is pathogenic for mice and rabbits, in which it may cause either a local abscess or a general septicemia.

Micrococcus tetragenus.—This organism was discovered by Gaffky* in the pulmonary cavities in phthisis. It has also been found in pure culture in abscesses in animals and man.† It often occurs in the healthy mouth. Morphologically M. tetragenus is distinguished by its occurrence in tetrads or groups consisting of four small oval cocci; it is Gram-positive (Fig. 47). In cultures the tabular arrangement is not always seen, but the flat tablets occur uniformly in the animal organism, where a rather heavy capsule surrounds the tetrad. On agar a confluent, rough, elevated white growth is produced. On potato a thick, white, slimy growth occurs. Gelatin is not liquefied; milk is coagulated.

White mice inoculated with M. tetragenus succumb to a rapidly progressing septicemia. Guinea-pigs and rabbits usually show only a local affection. House-mice and rats are rather immune. Forneaca‡ has reported a case of septicemia in man in which M. tetragenus was present in pure culture in the blood. It is not uncommonly found in suppurations of the mouth and neck.

* Gaffky: Mitt. a. d. k. Gesmt. Ber., 1881, 1, p. 1.

† Müller: Wien. klin. Wchnschr., 1904, 17, p. 815.

‡ Forneaca: Rif. Med., 1903, 19, p. 309.

CHAPTER XIV

THE ANTHRAX BACILLUS

Historical.—Anthrax,* or splenic fever (Fr., *charbon;* Ger., *Milzbrand*), is one of the best-known and longest studied of all bacterial diseases. As pointed out in the introductory chapter, the demonstration by Robert Koch † in 1876 of the causal relation between anthrax and a specific bacillus marks the beginning of modern bacteriology.‡ Prior to Koch's investigations, and as early as 1850, microscopic examinations by Davaine and Rayer,§ Pollender,‖ and others had shown that a rod-like organism was constantly present in the blood and organs of animals dying from splenic fever, and inoculation experiments with the blood of infected animals, leading to a reproduction of the typical disease with all its symptoms and lesions, had been successfully performed by Brauell.¶ To the inferences drawn from these observations and experiments there was raised the objection that not the rod-like organisms, but something else in the diseased blood, might have caused the effects produced by blood inoculation. It must be conceded that this argument, although without experimental basis, was logically well founded. Before Koch's work, therefore, rod-shaped bacteria had been observed in the bodies of animals suffering from anthrax, and their etiologic connection with the disease had, in the judgment

* The disease of cattle known as "symptomatic anthrax" has nothing to do with true anthrax. (See p. 322.)

† Koch: Cohn's Beiträge, 1877, 2, p. 277.

‡ A fair example of the views upon the causation of anthrax prevailing at an earlier period is found in the hypothesis of Delafond, a French veterinary surgeon, who held that the anthrax of sheep was due to "an excess of blood circulating in the vessels." Concluding that this was caused by a rich nitrogenous pasturage, he advised sheep-raisers as a prophylactic measure to put the animals on short rations. ("Life of Pasteur," New York, 1902, p. 69.)

§ Davaine and Rayer: Bull. soc. de biol., 1850, p. 141.

‖ Pollender: Vierteljahr. f. ger. Med., 1855, 8, p. 103.

¶ Brauell: Archiv f. path. Anat., 1857, 11, p. 132.

of many, been rendered highly probable, but it was not until Koch's researches appeared that medical opinion generally was impelled to the conviction that the anthrax bacillus was the cause of the specific disease with which it was associated. Koch reached this result by obtaining the anthrax bacillus apart from all foreign matter and freed from any of the tissue fluids or body-cells of the diseased animal from which it was derived. This achievement was due to his discovery that the anthrax bacillus would grow and multiply outside the body upon the aqueous humor of the ox's eye. By cultivating it upon this medium for a series of generations, and, after allowing sufficient intervals for multiplication, transferring it from tube to tube, a growth was finally obtained which not only was not mixed with any of the blood-corpuscles or other matter derived from the original source, but was composed simply of the descendants of the original rod-like organisms many generations removed. Experiments made with this pure culture showed that a well-characterized attack of splenic fever, with the appropriate symptoms and lesions, could be produced by the introduction of a pure culture of bacilli into the body of susceptible animals. Koch's observations upon the life-history of the anthrax bacilli also cleared up many of the difficulties and apparent paradoxes that had previously obscured the study of the disease. His discovery of the phenomenon of spore-formation, and of the part played by spores in the spread of the disease in nature, must be reckoned as one of the more important of these advances. It is known that previous workers had been greatly perplexed by the singular observation that occasionally specimens of blood which appeared not to contain any bacteria were nevertheless capable, on inoculation, of producing anthrax. This was satisfactorily explained by the discovery that spores, which are highly refractive and consequently visible with difficulty, had been formed in the blood in such cases after the blood had been drawn from the body. The prolonged vitality of the spores in soil, again, explained the persistence of the disease in certain localities and its reappearance in once-infected pastures after the lapse of many years.

Characteristics of the Anthrax Bacillus; Morphology.—The anthrax bacillus is one of the largest of the pathogenic bacteria and ranges from 4.5 μ to 10 μ in length and from 1 μ to 1.25 μ in breadth.

In cover-slip preparations from the blood or lymph of an infected animal the rods are usually single, but rarely two or three are united in short chains. Blood films and spleen pulp preparations when stained by special methods (Johne,* Räbiger †) reveal the presence of a *capsule.* The bacilli stain readily with the ordinary anilin dyes and retain the stain when treated by Gram's method. The ends of the rods are often concave and somewhat swollen, so that the appearance of a chain of anthrax bacilli has been often compared to a jointed bamboo fishing-rod (Fig. 48). When grown on artificial culture-media, threads and filaments, sometimes of extraordinary length, are produced, and it is often difficult to make out the limits of the individual rods of which the filaments are composed. After a varying period of growth, depending upon the temperature, nature of the nutrient medium, abundance of oxygen, and other factors, highly refractive bodies known as spores make their appearance in the interior of the rods.

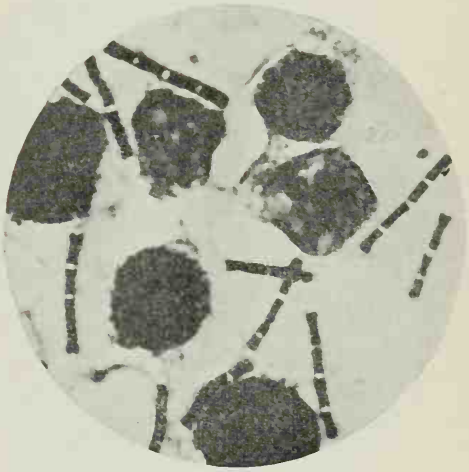


Fig. 48. — Bacillus anthracis in spleen pulp. Fuchsin stain; × 2000; C. Fränkel prep. (Kolle and Wassermann).

Spores and Spore-formation.—Owing to the fact that the spores of the anthrax bacilli are among the most resistant forms of pathogenic bacteria, they have long been favorite test objects for determining the efficiency of germicides and other destructive agencies, and much attention has in consequence been directed to their morphologic and biologic properties. Only a single spore is produced in each cell. It is formed in the middle of the cell, where it can be seen in unstained preparations as an oval or nearly spherical, highly refractive body of the same diameter as the rod (Fig. 49). The chemical composition of the spores is said to differ from that of the rods in containing a larger proportion of fatty substances and protein (spores, 77.75 per cent. protein; rods, 42.5 per cent.).

* Johne: Deut. Ztschr. f. Thiermed., 1893, 19, p. 244.

† Räbiger: Ztschr. f. Fleisch- u. Milchhyg., 1901, 11, p. 68.

Spores are produced only in the presence of free oxygen, and hence do not occur in the circulating blood of infected animals, but develop when blood is drawn, either during the course of the infection or after death, and allowed to stand in contact with the air. Spores may be formed between 14° and 40° C., but are developed most abundantly at 32° to 35° C. Germination is usually polar, that is, parallel with the long axis of the spore, but may be rarely equatorial. Like all spores, those of the anthrax bacilli resist drying for a prolonged period (at least ten to twelve years). They are not so resistant to heat as the spores of the closely allied B. subtilis and some other saprophytic forms, and, as a rule, are killed by dry heat in three hours at 140° C., and by steam or boiling water in five to ten minutes, although some resist for much longer periods. Anthrax spores are able to withstand the action of the ordinary germicides much better than the bacilli; thus, a 10 per cent. solution of creolin kills anthrax bacilli in ten to twenty minutes, but is not able to effect the death of anthrax spores, the latter being able to maintain their vitality even in a 60 per cent. solution.

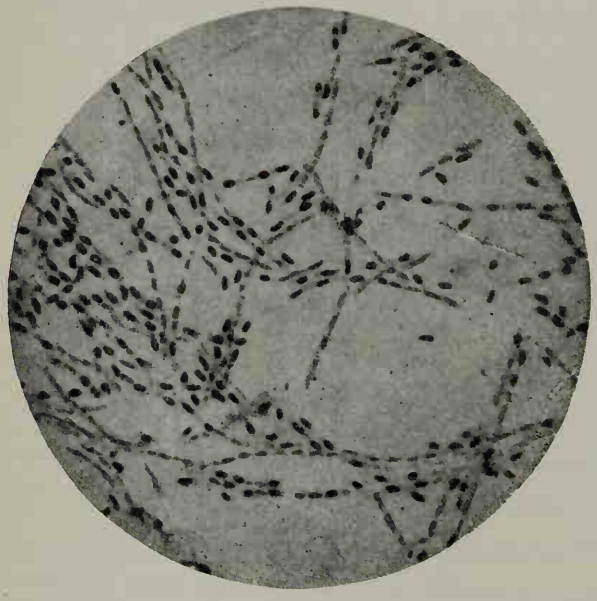


Fig. 49.—Bacillus anthracis with spores. Carbol-fuchsin and methylene-blue stain; × 1000 (Fränkel and Pfeiffer).

It is claimed that permanent asporogenous varieties of the anthrax bacillus have been obtained by various methods, such as growth in the presence of antiseptics (carbol-broth 1 : 1000, Roux*), at high temperatures (42° C., Phisalix †), and under other disadvantageous conditions, and that such non-spore-forming races are in other respects entirely normal, even to exhibiting a full measure

* Roux: Ann. de l'Inst. Past., 1890, 4, p. 25.

† Phisalix: Archiv d. Physiol., 1893, 5, p. 217.

of virulence. Some of the statements in regard to this matter, however, lack entire corroboration, and it must at present be regarded as doubtful whether permanently asporogenous but fully virulent and undegenerate varieties of the anthrax bacilli can be either artificially produced or exist in nature.

Growth Characteristics.—Upon the ordinary culture-media the anthrax bacillus grows freely under aërobic conditions and at ordinary temperatures. In broth, as a rule, no pellicle is produced

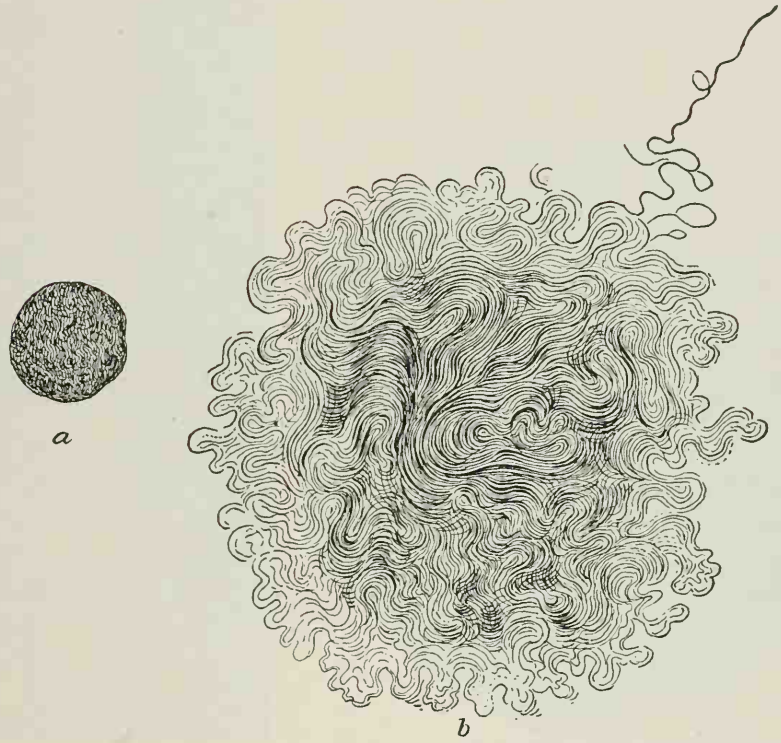


Fig. 50.—Deep (*a*) and surface (*b*) colony of anthrax on gelatin plate; × 80 (Flügge).

on the surface, but a heavy flocculent sediment is formed, the intervening layer of fluid in undisturbed cultures remaining quite clear; no indol is produced. The appearance of the colonies upon the surface of gelatin or agar plates is highly characteristic; long, wavy filaments project from the colony in every direction, and when viewed under the low power of the microscope, the thickly coiled masses have been likened to the snaky tresses of Medusa (Figs. 50 and 51). The same tendency to form filamentous outgrowths is seen in young gelatin stab-cultures, in which the "inverted fir-tree" appearance is of common occurrence (Fig. 52). Gelatin is slowly

liquefied. Milk is feebly acidified and is curdled by a rennet-like ferment, and the casein slowly peptonized. On potato a gray, furry growth is produced; spores are often formed in particular abundance on this medium.

Pathogenicity for the Lower Animals.—In nature anthrax is primarily a disease of cattle and sheep; horses and swine are susceptible, but are less commonly affected under natural conditions. In the German Empire in 1899 the following cases of anthrax were reported: 3678 cattle, 307 sheep, 282 horses, 61 swine, 6 goats. Wild deer and other gregarious herbivora are liable to occasional outbreaks. The smaller rodents are very sensitive to

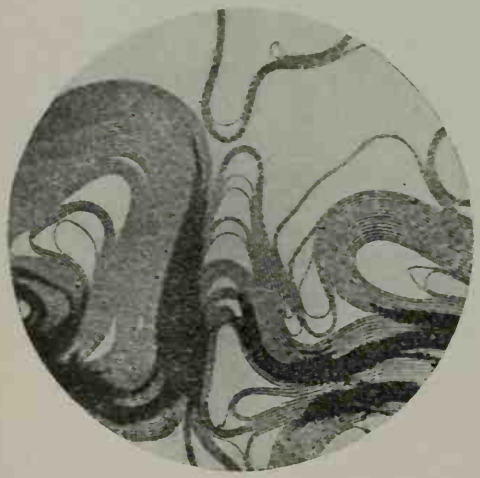


Fig. 51.—Bacillus anthracis, impression preparation, edge of colony; Zettnow prep. (Kolle and Wassermann).

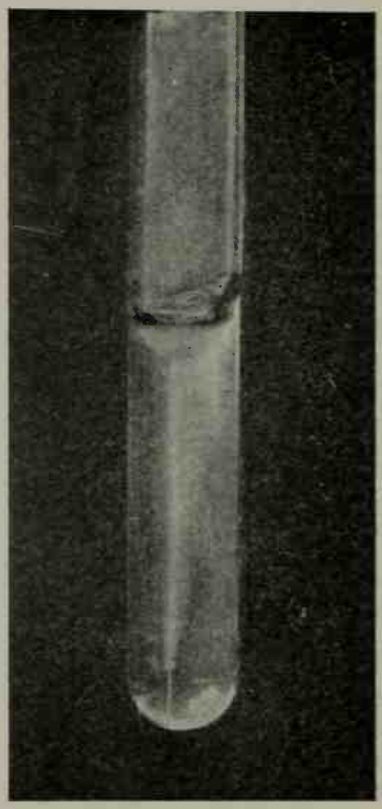


Fig. 52.—Bacillus anthracis, gelatin stab-culture.

inoculation. Rabbits, guinea-pigs, and white mice are susceptible in the order named, and are fatally affected by the subcutaneous introduction of a very small number of virulent bacilli. The white mouse is said to succumb to inoculation with a single germ of virulent strain. Carnivorous animals, although possessing greater resistance than the herbivora, are nevertheless susceptible, as several epidemics in zoölogical gardens have shown, leopards, lions, pumas, bears, and others perishing from the disease (Jensen,* Lange †).

* Jensen: Baumgarten, Jahresb., 1891, 7, p. 167 (cited).

† Lange: Hyg. Rundsch., 1901, 11, p. 529.

Certain animals possess marked natural resistance to anthrax. Rats are quite resistant, especially the white rat, only about 14 per cent. of the latter dying as the result of inoculation. The dog is only slightly susceptible. Birds, especially pigeons, can be infected, but not easily. Frogs are immune, but toads are very susceptible.

The route by which the germs enter the body exerts an important influence in both experimental and natural infection. Subcutaneous inoculation is the method most commonly practised in experimental work, and is almost uniformly fatal with the ordinary small laboratory animals. It has been frequently stated that intravenous and intraperitoneal inoculations are even more constantly and surely fatal than subcutaneous, but late researches cast doubt upon this view, and indicate that if great pains be taken to prevent subcutaneous infection during the course of the operation, animals can withstand the introduction of a considerable number of anthrax bacilli directly into the circulation or into the peritoneum. Feeding experiments show that administration of spore-free cultures even to highly susceptible animals is without result, owing to the destruction of the bacilli in the stomach. The feeding of spores, on the contrary, leads to infection of the more susceptible species, although not so certainly as subcutaneous inoculation. The more resistant species (for example, swine) are with difficulty infected through the alimentary tract. Infection through the respiratory tract is apparently possible, as far as the experimental results indicate, although it is probably almost unknown in the

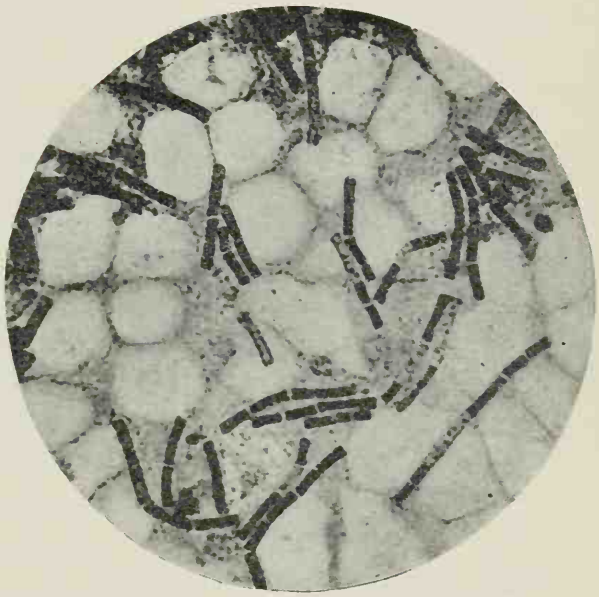


Fig. 53.—Bacillus anthracis in peritoneal fluid of a mouse; gentian-violet; × 1000 (Fränkel and Pfeiffer).

lower animals under ordinary conditions, and the views of experimenters are not wholly in accord.

In the very susceptible animals the disease runs a rapid course and presents all the characteristics of a typical septicemia (Fig. 53). Local manifestations may be almost entirely absent. Enormous multiplication of the bacteria takes place in the blood and internal organs, and sections through the liver or spleen show that the capillaries are gorged with masses of bacteria (Fig. 54). The spleen is of a deep-red color and is greatly enlarged, whence the appropriateness of the name splenic fever as applied to this disease in cattle. The more resistant animal species do not develop this generalized infection, but the bacteria remain localized in an abscess or carbuncle and fail to spread extensively through the body. This is the case in the dog and, as will be seen presently, in man also with certain forms of infection. In this respect anthrax furnishes an illustration of the general rule that when a bacterial invasion meets slight resistance from the animal tissues an abundant multiplication of the bacteria occurs throughout the body, while the possession of high powers of resistance is accompanied by a pronounced local reaction. Man stands perhaps midway in susceptibility between the dog and the sheep.

Fig. 54. — Bacillus anthracis. Section of spleen of mouse; × 500 (Günther).

Under natural conditions cattle and sheep are infected through the alimentary tract by swallowing spores while grazing in infected pastures. As has been pointed out, spores are able to retain their vitality in soil for a long period, and pastures once infected with the disease are able to communicate it to cattle after the lapse of many years (thirty years). Hides imported from China and other countries where the disease prevails are not uncommonly infected with anthrax spores, and in the United States several

outbreaks of anthrax among cattle, with some consequent cases of human infection, have been traced to the overflowing of pasture land by streams receiving the drainage of tanneries.*

Cattle may also occasionally be infected by direct contact through wounds, abrasions, and other injuries to the skin, but alimentary tract infection is by far the more usual.

Pathogenicity for Man.—Three modes of infection of human beings are known to occur—(*a*) through the skin, (*b*) through the respiratory tract, and (*c*) through the alimentary tract. The bacillus is almost always transmitted to man through the agency of the lower animals rather than through other human beings. Persons having to do with cattle and their products, such as butchers, shepherds and herdsmen, handlers of hides, hair, and fleeces, are most commonly affected.

(*a*) *Malignant Pustule.*—The most common form of anthrax in the human subject is due to skin infection, and usually takes the form of a localized boil or abscess, which often heals spontaneously, but may progress into a septicemic condition unless checked by incision or other surgical procedure. The handling of infected hides or carcasses constitutes the ordinary means of infection. Porters on the London docks, who carry on their naked backs hides imported from South American or Asiatic ports, sometimes develop malignant carbuncles as a result of anthrax infection through dorsal abrasions or scratches. Owing to the relatively high resistance of man, septicemia does not often occur, especially if the carbuncle be incised and thoroughly cleansed. Lesions of all sizes may be produced, from a minute pustule to a large and angry abscess.

(*b*) *Pulmonary Anthrax.*—The pulmonary form of anthrax due to inhalation is the most dangerous, although not the most common, variety of the disease in man. The name currently applied to this variety of anthrax in England is "woolsorter's disease," and, as the name implies, the affection is usually caused by inhalation of the spores set floating in the air during the handling and sorting of wools and fleeces. It is characterized by many of the symptoms of pneumonia and often passes over into a fatal septicemia.

* Ravenel: Rep. Amer. Pub. Health Assoc., 1898, 24, p. 302; Russell, Seventeenth Ann. Rept. of Wisconsin Agr. Expt. Station, 1900, p. 171; Gärtner and Dammann, Arb. a. d. k. Ges., 1907, 25, p. 416.

(*c*) *Intestinal Anthrax.*—Although the usual path of infection in cattle, the alimentary tract is very rarely so in man. A few instances are on record of the causation of intestinal anthrax through the medium of spore-infected food. Such cases have usually occurred among workers with animal products, and have probably been due to lack of caution in handling food with uncleansed hands. Insufficiently cooked meat from anthrax-infected animals may also be a source of intestinal anthrax.

Mode by which the Anthrax Bacillus Causes Injury to the Animal Organism.—In the typical form of anthrax septicemia bacilli are found in immense numbers clogging the capillaries, and apparently by their accumulation hindering the circulation of the blood. This fact caused the theory to be advanced very early that death in such cases was due to a kind of internal suffocation. This view, however, finds no support in the character of the symptoms of anthrax. Death, moreover, frequently occurs in some animals in the absence of any noteworthy number of bacteria within the blood-vessels. This is particularly true in fatal cases of anthrax in man. It might seem from analogy that we should find that the anthrax bacillus secretes a soluble toxin such as is formed by the diphtheria bacillus and some other pathogenic microbes, and many of the phenomena of anthrax infection seem to point to the action of such a substance. All attempts, however, to demonstrate the existence of either an extracellular or an intracellular anthrax toxin have been unsuccessful, and, although all the probabilities are in favor of the existence of some such substance, the exact manner in which the anthrax bacillus damages the animal organism remains at present a mystery.

Immunity.—Some natural susceptibility to anthrax is possessed by many animals; the degree of such susceptibility may be heightened or diminished by a great variety of factors. Normal susceptibility, for example, may be lessened by the injection of thymus extract and other organic substances, and also by certain operative procedures, such as section of the sciatic nerve. Susceptibility may be increased by a number of physiologic influences, such as alteration of the normal body-temperature, as in Pasteur's classic experiment with refrigerated fowls, which under normal conditions are immune to inoculation, but succumb when chilled; the frog, con-

versely, which is normally without susceptibility, becomes susceptible when kept at a high temperature. Lowering the temperature of mammals with drugs, such as antipyrin, has a depressing influence on the power of resistance. Administration of other drugs, such as alcohol, phloridzin, and chloroform, feeding with unsuitable or insufficient food, subjection to excessive fatigue, and other factors all increase susceptibility.

The cause of the high natural immunity to anthrax possessed by the dog, fowl, and certain other animals has been the object of much experimentation. No antitoxin is present in the blood of naturally immune animals. The body-fluids of some species manifest bactericidal powers toward the anthrax bacillus, but there is no concurrence between the degree of immunity and the anthracidal power of the blood-serum. The blood-serum of the highly susceptible rabbit, outside the body, is strongly bactericidal, but anthrax bacilli injected into the circulation seem to multiply freely in the blood-stream. Blood taken from the very resistant dog and fowl is practically devoid of bactericidal properties. Bail and Petterson * have attempted to explain the absence of bactericidal power in the drawn blood of the latter animals by supposing that the constituent known as the complement, which, within the dog, is supplied by the leukocytes, is lacking in the drawn blood. As evidencing this, they show that addition of a suitable complement to dog's serum, either in the guise of rabbit serum or of canine leukocytes, imparts to the dog's serum a strong germicidal power. On the other hand, the bactericidal action manifested by rabbit serum outside the body is supposed to be restrained within the body by the presence of a substance which binds the amboceptor and so prevents the destruction of the anthrax bacilli. Future investigation must determine how far this view is correct.

The share of phagocytosis in natural immunity is likewise under discussion. As has been shown by Hektoen,† it is highly probable that the natural immunity of the dog is due to phagocytosis. The destruction of virulent anthrax bacilli that takes place in mixtures of normal serum and washed blood-corpuscles is accompanied by marked phagocytosis. Neither normal serum alone nor suspensions

* Bail and Petterson: Centralbl. f. Bakt., 1903, 33, p. 756.

† Hektoen: Jour. Amer. Med. Assoc., 1906, 46, p. 1407.

of washed corpuscles can prevent the multiplication of the bacteria, and it seems reasonable to conclude that the normal serum contains an opsonin or sensitizing substance which prepares the bacilli for the onslaught of the phagocytes. Other experimental evidence for this view is contained in the article just cited.

Vaccination Against Anthrax.—Animals naturally susceptible may be made immune by artificial means, and domestic animals have been largely protected against anthrax in this way. Pasteur devised a method for vaccinating cattle and sheep against anthrax which is dependent on the subcutaneous inoculation of attenuated cultures. Two vaccines were used. The "first vaccine" consisted of a broth culture whose virulence was so greatly diminished by heat that it would no longer surely kill guinea-pigs, although it was still fatal for white mice. After twelve days a second inoculation was made with the "second vaccine," which was of such a strength that it would kill guinea-pigs but not rabbits. Following inoculation with these two vaccines, a fully virulent culture could be injected with impunity. In spite of some accidents due to the use of imperfectly standardized vaccines, this method of protective inoculation has proved, on the whole, of great practical value. In France 30,000 to 50,000 cattle and horses and 250,000 to 350,000 sheep are vaccinated annually. It is estimated that many thousands of animals are saved by this procedure. Active immunization of rabbits and guinea-pigs can also be effected by the injection of attenuated cultures, but with much greater difficulty.

The serum of actively immunized animals contains specific protective substances. Inoculation with the blood-serum of an actively immunized animal confers some degree of protection against anthrax infection, and in the hands of Sobernheim,* Sclavo,† and others has been attended as well with some measure of therapeutic success; that is, injection of the serum will save the life of animals even when the anthrax bacilli have already entered the circulation. Very favorable reports of the use of Sclavo's serum in cases of anthrax in man have come from Italy and from South America.

* Sobernheim: Ztschr. f. Hyg., 1897, 25, p. 301; Centralbl. f. Bakt., 1899, 25, p. 840.

† Sclavo: Centralbl. f. Bakt., 1899, 26, p. 425.

The mechanism by which the protective serum exerts its action is not certainly known. With our present knowledge, perhaps the most reasonable view is that which would look upon anthrax immunity as a phagocytic immunity and the function of the immune serum as sensitizing or opsonic.

A combination of the active and passive methods of immunization has been used in parts of South America for dealing with large numbers of cattle, and is said to possess the advantage of effecting the desired result in a few days and with a single treatment.

Bacillus Subtilis.—The common bacillus of hay infusion, B. subtilis, is culturally and morphologically very similar to B. anthracis. The spores, however, germinate equatorially instead of at the pole. A heavy tenacious pellicle is formed in broth cultures; gelatin and casein are liquefied more rapidly than by B. anthracis. B. subtilis is widely distributed in earth, air, and water, and was formerly regarded as one of the most typical of "non-pathogenic" organisms. The first report of any pathogenic power on the part of this germ was made by Charrin and de Nittis,* who cultivated B. subtilis upon blood-media and passed it through animals until it had acquired considerable virulence. The hay bacillus is also capable of producing spontaneous infection in man, as shown by Baenziger and Silberschmidt,† who found the organism in pure culture in a case of panophthalmitis following penetration of the cornea by a piece of steel. They reproduced the disease in rabbits and regained the

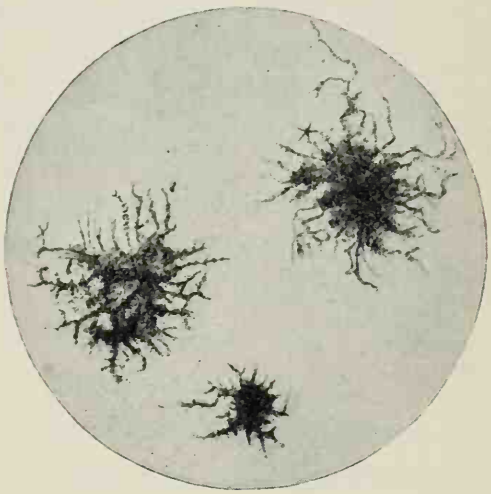


Fig. 55.—Bacillus subtilis from panophthalmitis; agar colonies; × 30 (Axenfeld).

* Charrin and de Nittis: C. r. soc. biol., 1897, 49, p. 711.

† Baenziger and Silberschmidt: Bericht der ophthal. Gesellschaft, Heidelberg, 1902.

organism. More recently Silberschmidt * and others † have described several such cases. The toxic result of infection is believed to be due to some substance in the bodies of the bacilli, since the filtrates of cultures have little or no effect.

Before methods of studying bacteria had become as elaborate and well tested as they now are, the close resemblance of B. subtilis and B. anthracis led to a belief that these organisms were simply closely related varieties and could be transformed one into the other. Buchner in 1880 maintained that he had succeeded in changing the virulent anthrax bacillus into the common hay bacillus and *vice versâ*. His assertions seem to have been based largely upon the fact that the anthrax bacillus may be attenuated or made less virulent by a variety of methods, and also upon an insufficient knowledge of the biologic differences between the two species.

The so-called potato bacillus (B. mesentericus) and a number of other aërobic spore-bearing bacilli found in water and soil may be ranked in the B. subtilis group.

* Silberschmidt: Ann. de l'Inst. Past., 1903, 17, p. 268.

† Kayser: Centralbl. f. Bakt., 1903, 33, p. 241; Kneass and Sailer: Univ. Penna. Med. Bull., 1902, 16, p. 131.

CHAPTER XV

THE DIPHTHERIA BACILLUS

The discovery of the bacillus of diphtheria and the study of this organism and its products have profoundly affected both the mode of treatment of the disease and the manner of combating its spread.

(1) Early recognition of the real nature of a throat infection is necessary for its proper treatment, and we are now able to distinguish with certainty the highly dangerous class of throat affections caused by the diphtheria bacillus from clinically similar but less dangerous anginas that are due to a different cause. In a word, the finding of B. diphtheriæ enables a correct diagnosis to be made. (2) Investigation of the physiologic properties of the diphtheria bacillus has led directly to the discovery of the diphtheria antitoxin, a specific remedy of unquestioned value. (3) By systematic bacteriologic examination of the throats of convalescents it is possible for health officials to fix the term of necessary quarantine with much more precision than formerly. The power to do this is an invaluable aid in limiting the spread of the disease.

The earliest description of the diphtheria bacillus appears to have been given by Klebs* in 1883, but the etiologic relations of this organism first came into notice through the investigations of Löffler, published in 1884.† Löffler succeeded in obtaining in pure culture from a number of cases of diphtheria the bacillus seen by Klebs. Although Löffler's observations favored the view that the bacillus thus cultivated was the cause of diphtheria, Löffler expressly disclaimed the assumption that this was actually the case, largely on the ground that the bacillus was not found in all cases of clinical diphtheria, while, on the other hand, it had been found by him in the throat of a perfectly healthy child. The significance of such findings is now more clearly understood. A similarity of clinical symptoms does not always betoken causal identity. So far as the local manifestations are concerned, streptococci can pro-

* Klebs: Verhandlungen des Congresses f. innere Med., 1883.

† Löffler: Mitt. a. d. kais. Gesund., 1884, 2, p. 421.

duce a condition apparently indistinguishable from that in which the Klebs-Löffler bacillus is found. Again, it is now known that the diphtheria bacillus is occasionally present in the healthy throat of persons associated with diphtheria patients. Continued investigation by various observers showed that the Klebs-Löffler bacillus was always present in the typical false membrane of diphtheria, and in 1888–89 Roux and Yersin * triumphantly demonstrated the etiologic relation of the bacillus to the disease by showing that it formed a toxin which was capable of reproducing with singular fidelity the characteristic symptoms and lesions.

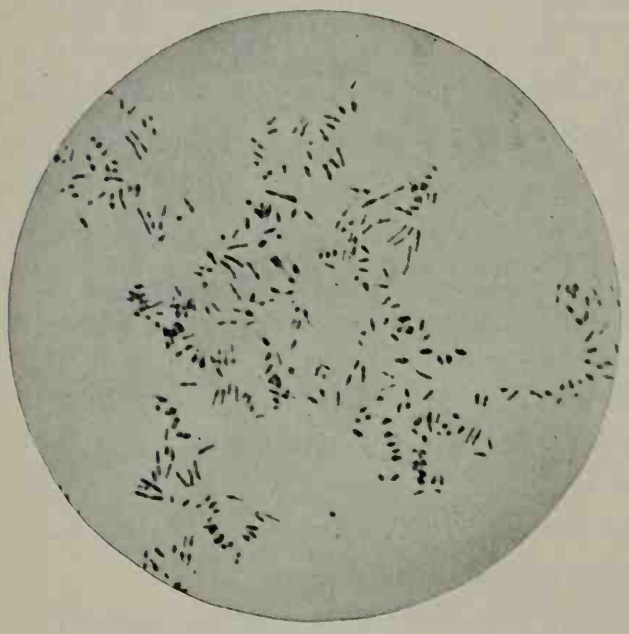


Fig. 56.—Bacillus diphtheriæ; twenty-four-hour broth culture; Löffler's methylene-blue; × 1000 (Beck, Kolle and Wassermann).

Morphology.—The diphtheria bacillus is a slender rod ranging from 1 μ to about 6 μ in length. When stained with Löffler's methylene-blue, it usually presents a beaded, striated, or granular appearance, which is so characteristic that by simple microscopic examination a trained observer can recognize the Klebs-Löffler bacillus in cultures from a suspicious throat (Fig. 56). In cover-slip preparations made directly from the false membrane the uneven staining of the cell protoplasm is less noticeable than in preparations from cultures. Club-shaped forms are sometimes observed in films made from the membrane, but less frequently than in films from nutrient media; in the latter, bacilli with swollen and deeply stained ends are, as a rule, abundant (Fig. 57). Bacilli containing metachromatic granules are commonly observed in cultures derived directly from clinical cases. Many recent observers recognize different morphologic types of B. diphtheriæ. In the

* Roux and Yersin: Ann. de l'Inst. Past. 1888, 2, p. 629.

nose and throat of both healthy and diphtheritic persons diphtheria bacilli, known as the "barred" and "solid" types, are found (Wesbrook*) (Fig. 58). The distinction is based upon a difference in behavior toward stains. The protoplasm of the so-

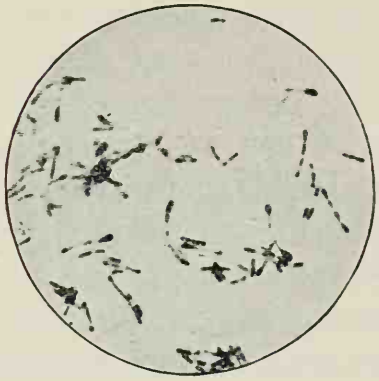


Fig. 57.—Bacillus diphtheriæ; blood-serum culture showing clubbed ends and irregular staining; methylene-blue; × 1100 (Park).

called solid form stains uniformly and shows neither bars nor granules. The protoplasm of the barred form stains in irregular blocks or segments, the intervening portion taking the stain slightly or not at all. The barred or striated type is said to

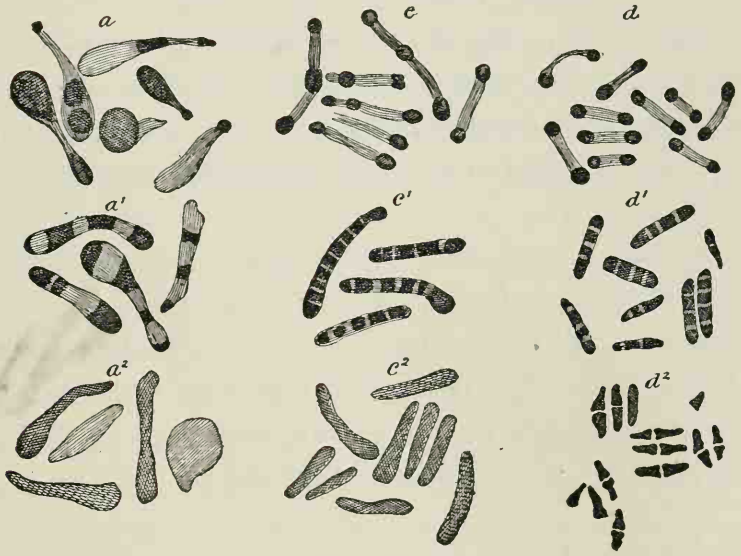


Fig. 58.—Wesbrook's types of Bacillus diphtheriæ: *a*, *c*, *d*, Granular types; a^1, c^1, d^1, barred types; a^2, c^2, d^2, solid types; × 1500.

be frequently present on the conjunctiva, and when isolated from a form of conjunctivitis known as xerosis, is usually denoted

* Wesbrook, Wilson, and McDaniel: Trans. Assoc. Amer. Physicians, 1900; see also Gorham: Jour. Med. Res., 1901, 6, p. 201.

as the *xerosis bacillus*. The term xerosis bacillus has, however, been loosely used, and a number of different kinds of organisms have been sometimes put under this head. It is stated that barred forms are sometimes found in clinical diphtheria as the sole type, but this condition appears to be very rare. The relation of the solid type to clinical diphtheria is still obscure. By some authorities the solid forms are classed as pseudo-diphtheria bacilli and are not regarded as capable of causing diphtheria. The barred and solid types are found much more commonly than the granular type in the nose and throat of healthy individuals.

The granular type, on the other hand, predominates in clinically characteristic diphtheria. Several observers report that during convalescence the granular type is gradually replaced by the solid, a fact that has been regarded as pointing to a gradual morphologic alteration brought about by the influence of the body-fluids of an immune individual.*

In some cultures of the diphtheria bacillus true branching has been observed. The branching apparently originates by budding, and is sometimes followed by degeneration of the parent stem at the point of origin. Sometimes very complex branching forms are produced (Hill). By the use of the hanging-block method of cultivation Hill † has observed so-called post-fission movements in B. diphtheriæ. After cell division a sudden snapping across of the rod occurs, which seems to be strictly characteristic of the organisms of this group.

The diphtheria bacillus exhibits a marked tendency to the production of involution forms. These occur especially abundantly in cultures on artificial media: for example, on blood-serum after five to seven days. The biologic significance of the appearance of involution forms as well as of branching forms among the diphtheria bacilli and certain other groups of bacteria is not at present understood.

B. diphtheriæ does not form spores and does not possess the power of movement. When tested by Gram's method most races retain the stain.

* An excellent discussion of morphologic types of B. diphtheriæ and their significance in public health work is given in the Amer. Jour. of Pub. Hyg., 1907, 17, p. 156.

† Hill: Jour. Med. Res., 1902, 7, p. 202.

Neisser * has devised a special staining method that has been considered by some to be differential. The cover-slip films are first treated for one to three seconds with a methylene-blue solution (1 gram Grübler's methylene-blue is dissolved in 20 c.c. of 96 per cent. alcohol, and to this solution is added 950 c.c. of water and 50 c.c. of glacial acetic acid). After washing the films with water they are stained with a second solution (2 gr. Bismarck-brown dissolved in 1000 c.c. of water, or 1 gr. chrysoidin in 300 c.c. hot water and filtered) and again washed. Schiller † recommends lengthening the action of each stain to from ten to fifteen seconds. When this staining method is applied to cultures grown upon Löffler's serum the method gives fairly good results, and undoubtedly aids in diagnosis, but it does not permit the sharp distinction to be made between diphtheria and pseudo-diphtheria bacilli that was originally claimed for it. Many other special methods of staining this organism have been employed with more or less success, but few of them have been found so satisfactory as the long-used Löffler methylene-blue (p. 46).

Cultural Characteristics.—The diphtheria bacillus grows quite rapidly upon appropriate nutrient media, provided a suitable temperature—not less than 19° C.—be maintained. The optimum is about 37° C. The reaction of the medium is a feature to which this organism is peculiarly sensitive, a reaction that is about 1 per cent. acid to phenolphthalein or slightly but distinctly alkaline to litmus, being necessary both for growth and for toxin production. An abundant oxygen supply is likewise a requisite. The blood-serum medium recommended by Löffler is ordinarily employed for isolation. *Löffler's serum* consists of a mixture of three parts of calf or sheep serum with one part of 1 per cent. glucose broth. On this medium the diphtheria bacilli grow rapidly at 37° C., often forming minute but visible colonies inside of twelve hours; within eighteen to twenty hours small opaque gray colonies are plainly seen on the surface, and from a microscopic examination of cover-slip films made from these colonies diagnosis is almost invariably possible. Other organisms that may have been present

* Neisser: Zeitschr. f. Hyg., 1897, 24, p. 443.

† Schiller: Kolle and Wassermann, Handbuch, Ergänzungsband 2, p. 107.

in the throat or in the false membrane are usually outstripped by the diphtheria bacillus in growth on Löffler's serum. Upon ordinary nutrient gelatin and agar the diphtheria bacillus is also able to develop, but less luxuriantly; gelatin is not liquefied by the growth. The surface colonies on agar, when viewed with a low magnification, are coarsely granular and somewhat irregular in outline, with ragged or fringed edges (Fig. 60). In milk abundant growth occurs with feeble acid reaction, but the lactose is not fermented and no

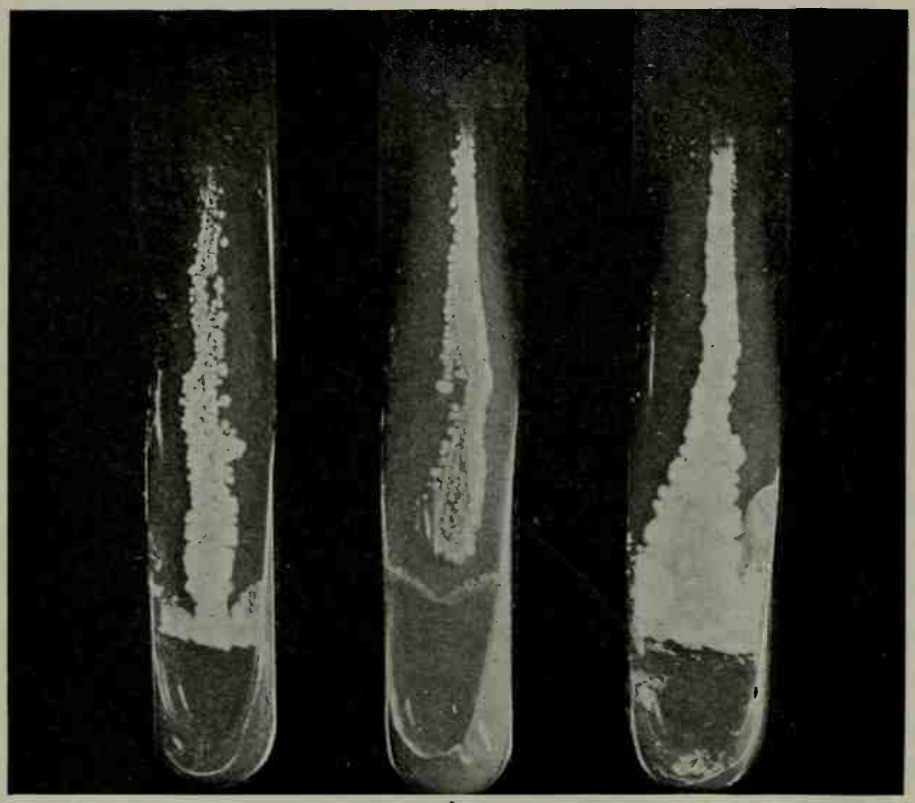


Fig. 59.—Diphtheria bacilli (from photographs taken by Prof. E. K. Dunham, Carnegie Laboratory, New York): *a*, Pseudobacillus; *b*, true bacillus; *c*, pseudobacillus.

curdling of the milk takes place. The acid reaction of potato is not favorable to growth. In broth containing dextrose an acid reaction is produced by the majority of the granular, virulent forms, while nearly all of the solid-staining forms that are encountered are unable to ferment dextrose. The distinction, however, does not seem to be an absolute one. Nitrate is reduced to nitrite by most strains of B. diphtheriæ; indol is not produced.

Resistance.—In growths upon the ordinary culture-media

the bacillus may retain its vitality for a long time. On agar it may live for six to eight weeks, on ordinary blood-serum, five to six months, and on dextrose blood-serum (Beck*), twelve to fifteen months. Although virulence ordinarily becomes lessened in cultures, many strains conserve their full virulence under prolonged cultivation. Löffler has recorded one instance where virulence was maintained during seventy-seven transfers, covering a period of twenty-seven months. In the dried diphtheritic membrane life can be maintained for a long period. Some observers have isolated bacilli from fragments of dried membrane after the lapse of several months.

Heat kills the bacilli rather readily. According to Brieger and Fränkel,† exposure to moist heat for forty-five minutes at 55° C. proves fatal. In the dry membrane they are much more resistant and are said to have withstood exposure to 98° C. for an hour.

The Diphtheria Bacillus in the Human Body.—Mucous surfaces are a favorite site for the growth of the diphtheria bacillus. The pharynx is the locality most commonly affected, but diphtheria of the larynx or membranous croup, and nasal diphtheria or membranous rhinitis, are by no means infrequent. The nose probably often serves as the portal of entry. Diphtheria of the conjunctiva sometimes occurs as the result of a diphtheritic patient coughing or sneezing into the eyes of the attendant physician or nurse. Diphtheritic infection of the middle ear is not uncommon. Infection of the mucous surfaces of the genital organs is occasionally met with. Primary infection of the lungs may occasionally occur, but is very rare. Apparently simple "colds" are sometimes due to the diphtheria bacillus. Although the diphtheria bacillus sometimes finds its way into the general circulation and gives rise to septicemia, it remains, as a rule, confined to the mucous surfaces. The symptoms and lesions produced are due partly to the presence of the bacillus and partly to its toxin. The chief local consequence of infection is a degeneration of the epithelial cells, extending to the underlying tissues and accompanied by a profuse fibrinous exudation. As a result

* Beck: Kolle and Wassermann, Handbuch, 2, p. 777.

† Brieger and Fränkel: Berl. klin. Wochenschr., 1890, 27, p. 241.

the characteristic diphtheritic membrane, containing fibrin, dead tissue-cells, leukocytes, and bacteria, is formed on the affected surface. The diphtheria toxin doubtless has a share in the formation of the membrane, but the most serious injuries that it causes are the systemic lesions due to its absorption. Diphtheria is a typical toxemia. The most severe lesions are produced in the heart, nerves, and kidneys. A variety of lesions may be found in the kidneys, acute interstitial nephritis being the most common. It is an old observation that albumin is found quite often in the urine of diphtheria patients; there is therefore no reason for attributing this symptom to the administration of diphtheria antitoxin; as a matter of fact, tests have shown that the amount of albumin in the urine is sometimes diminished after antitoxin is given. The lesions in the heart consist commonly of a fatty degeneration of the muscle-fibers, which may be very extensive. Fatty degeneration also occurs both in the myelin sheath of the peripheral nerves and in the white matter of the brain and cord. These changes in muscle and nerve seem to explain the nature of the grave cardiac weakness often observed in diphtheria, and also the frequent occurrence of the more or less extensive paralysis which so commonly follows a diphtheritic attack. Here too lies the explanation of the sudden fatal termination of many cases of diphtheria regarded as "mild" or even not recognized as true diphtheria. A small amount of toxin can probably cause extensive damage to vital tissues. "A patch of membrane the size of a thumbnail on the tonsil may generate sufficient toxin to cause death" (McCollom*).

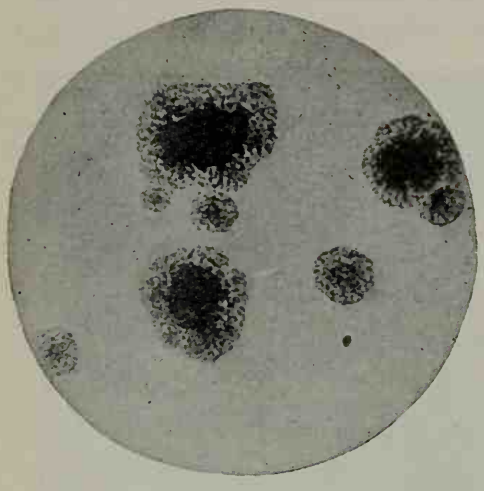


Fig. 60. — Bacillus diphtheriæ colonies on glycerin-agar, twenty-two hours old; × 39 (Heim).

Animal Inoculations.—Both the general and local symptoms of diphtheria can be reproduced by animal inoculation. Guinea-

* McCollom: Osler's "Modern Medicine," Phila., 1907, 2, p. 411.

pigs are readily killed by subcutaneous injection of a young broth culture, death usually occurring within two or three days after they are inoculated with a few drops of a twenty-four-hour broth culture of a virulent strain. Nephritic symptoms, paralytic manifestations, and other characteristic features of human diphtheria have been observed in the guinea-pig and other animals. An enlarged and hemorrhagic condition of the adrenals characterizes diphtheritic intoxication in guinea-pigs. Paralytic manifestations appear more frequently in dogs and in pigeons than in guinea-pigs or rabbits. As a rule, the bacilli remain localized and are not found in large numbers in the internal organs of the infected animals. Inoculations upon the healthy mucous membrane of most adult animals lead to no changes, but if young animals be injected intratracheally or if the mucous surface be injured before inoculation a characteristic false membrane is produced. The membrane produced experimentally is histologically identical with that found in cases of human diphtheria. Animals vary considerably in their susceptibility to infection. Rats and mice are relatively refractory; rabbits are less susceptible than guinea-pigs; cats, dogs, and pigeons are highly susceptible. When the bacilli are introduced into the alimentary tract, the result is negative, owing doubtless to the inability of the bacilli to effect a lodgment on uninjured epithelial surfaces. The bacilli are never found in any considerable abundance in the blood, and they appear only exceptionally to invade the tissues; injury to the organism, as a rule, results from the absorption of the toxin formed in the false membrane rather than from the presence of the bacilli in important organs.

The Diphtheria Toxin.—When B. diphtheriæ is grown in ordinary nutrient broth a soluble toxin is formed which diffuses out from the bodies of the bacilli during life into the surrounding medium. The toxin is present in hardly diminished strength in the sterile filtrate of a broth culture. The formation of toxin is interfered with by a persistent acid reaction, and hence if muscle-sugar is present in the broth in considerable quantity, the acid produced by its fermentation hinders materially the accumulation of toxin. In order to obtain maximum toxin production, the earlier experimental

procedures involved passing a current of air over the surface of broth cultures, the purpose of this being to facilitate the oxidation of the acid products of growth. The use of broth freed from muscle-sugar (p. 30) renders this device less essential, although the free access of air to the cultures is still recognized as important. The broth for toxin production should be in a thin layer in a wide-mouthed flask. Theobald Smith * has shown that the addition of a very small amount of dextrose, not exceeding 0.2 per cent., to broth previously freed from muscle-sugar favors toxin production. Other conditions, such as a temperature of about 36° C. and an abundance of peptone (2 per cent. Witte's peptone) or other albuminous substances and a well-developed surface growth, favorably influence toxin production. The toxicity, as a rule, attains a maximum in about five to ten days, depending upon the race used. Different races of diphtheria bacilli vary strikingly in their toxin-forming power. Certain strains that have been found to yield permanently an especially potent toxin are in widespread use in establishments for the manufacture of diphtheria antitoxin. Some of these strains generate so powerful a toxin that 0.001 c.c. of a filtered broth culture proves fatal to a guinea-pig, while other strains may generate so little that several cubic centimeters are necessary to produce a fatal result.

Little or nothing is known regarding the chemical nature of diphtheria toxin. It is destroyed by boiling for five minutes, and is greatly weakened by lower temperatures (60° to 70° C.). Direct sunlight causes a complete loss of toxicity within a few hours. When the toxin is kept in the dark and in cold storage, it may retain its activity for a long period—according to Abba † as long as two years. Roux and Yersin ‡ showed that the addition of a small amount of acid to a toxin filtrate caused the toxic property to disappear, but that if the acid were not allowed to act too long, the toxicity was regained on restoring the original reaction. The toxic body is precipitated by alcohol and by calcium chlorid, calcium phosphate, ammonium sulfate, and other protein precipi-

* Smith, Theobald: Jour. Exp. Med., 1899, 4, p. 373.

† Abba: Centralbl. f. Bakt., 1898, 23, p. 934.

‡ Roux and Yersin: Ann. de l'Inst. Past., 1889, 3, p. 273.

tants, but it is probably not itself a protein substance. Neither is the presence of protein necessary for its formation. Guinochet * has shown that toxin is formed when diphtheria bacilli are grown in urine that is free from albuminous constituents. Uschinsky † found that toxin is produced in a protein-free medium containing only ammonium lactate, sodium asparaginate, glycerin, and some simple mineral salts.‡

The toxin in some respects resembles an enzyme, but objections have been urged against the view that it is itself an enzyme. Such are its relatively high resistance to heat, the direct relation between the amount of toxin and the toxic effect produced as compared with the unlimited capabilities of true enzymes (Behring §), and other features not in harmony with the ordinary conceptions of enzymes. Much light has been thrown by Ehrlich upon the constitution of the diphtheria toxin. The facts that have led to a belief in the complex nature of the diphtheria toxin, and the hypotheses that have thrown light upon its probable composition and mode of action, are detailed elsewhere (pp. 101, 152).

The effects produced in animals by inoculation with a sterile toxin are wonderfully similar to those produced by infection with living bacilli, save that no false membrane is formed by the toxin alone. The other symptoms that are evoked are practically identical whether bacilli or toxin be employed. The histologic lesions which occur in the heart and other organs, and are found both in cases of human diphtheria and in animals inoculated with diphtheria bacilli, are reproduced by the germ-free toxin. There is no escape, therefore, from the conclusion that in diphtheria the chief injury to the animal organism is brought about by the action of potent poison which is secreted during the life of the bacillus and

* Guinochet: Archiv. de med. exp., 1892, 4, p. 487.

† Uschinsky: Loc. cit.

‡ Hadley (Jour. Infect. Dis., Supplm. No. 3, p. 95) obtained abundant toxin production in sixteen days on the following medium: sodium chloride, 0.6 per cent.; calcium chlorid, 0.08 per cent.; magnesium sulfate, 0.32 per cent.; dipotassium phosphate, 0.23 per cent.; ammonium lactate, 0.75 per cent.; glycerin, 3.4 per cent.; glycocol, 0.1 per cent., in distilled water.

§ Behring: "Geschichte der Diphtherie," Leipzig, 1893.

diffuses from the bacterial cell into the surrounding medium. Under certain conditions the human throat affords a lodging-place where the diphtheria bacillus is abundantly supplied with food, where it finds a highly suitable temperature for its growth and toxin-production, and where it is perhaps also benefited by the current of warm, moist air passing over the surface. That toxin is formed in the false membrane, whence it passes into the underlying tissues and diffuses through the body, causing injury to certain tissue cells for which it possesses a special chemical affinity, is a supposition quite in accord with all the observed facts.

Diphtheria Antitoxin.—Behring and Kitasato,* in 1890, found that the serum of rabbits immunized against diphtheria and tetanus by inoculation first with attenuated then with virulent cultures, contained a substance capable of neutralizing the effects of infection or intoxication in other animals. The action was found to be specific. The practical importance of this discovery in the case of diphtheria was soon made evident by the further researches of Behring, Wernicke, Knorr, Roux and Martin, and others.† The active principle in the blood and blood-serum is still chemically unknown, but from its neutralizing power it has been designated the diphtheria antitoxin. Somewhat later it was found that small non-fatal doses of toxin injected into the susceptible body were as effective in producing antitoxin as inoculation with the bacilli themselves, and that for antitoxin production on a large scale the horse could be used advantageously instead of the sheep. The amount of antitoxin that appears in the blood increases up to a certain point in proportion to increasing doses of the toxin, but the physiologic capacities of each individual animal limit the total amount of antitoxin produced. The antitoxic substance persists in the blood or blood-serum for a considerable period after the blood is drawn. It has been shown that the serum obtained from an immunized animal may retain unimpaired for many months its power

* Behring and Kitasato: Deut. med. Wchnschr., 1890, 16, pp. 1113, 1145; also Behring: "Die Blutserumtherapie," Berlin, 1902.

† For references to these see Roux and Martin: Ann. de l'Inst. Past., 1894, 8, p. 609.

of neutralizing diphtheria toxin when properly protected against putrefaction and the action of light or of high temperature. The probable mode of action of the antitoxin, and other theoretical considerations, have been treated in the chapter on Immunity (p. 135).

In the preparation of diphtheria antitoxin on a large scale certain procedures are generally followed. Horses have been found especially suited for antitoxin production, both on account of their size and their relative endurance to the treatment with toxin. As a rule, gradually increasing quantities of toxin are injected into the subcutaneous tissue of the horse at intervals of five to seven days during a period of about two or three months. Not all animals prove equally tolerant of the treatment or yield a satisfactory quantity of antitoxin, and a continued selection of the particularly well adapted animals goes on in every large establishment. When the antitoxin in the blood reaches a desirable potency, for example if the blood contains over 300 units per cubic centimeter, blood is drawn from the jugular vein into sterile glass jars and allowed to clot; from five to eight liters may be drawn at a time without injury to the animal, and bleeding may be repeated as often as once a month. The serum that separates from the clot is drawn off aseptically. It is then usually filtered through a Berkefeld filter, protected against contamination by the addition of carbolic acid, chloroform, or tricresol, tested and standardized, and is bottled or placed in syringes as the diphtheria antitoxin of commerce. If diphtheria antitoxin is kept in the dark and at a low temperature, it loses strength very gradually. Some sera show hardly any decrease in potency during periods of a year or more. Those sera containing the largest number of units per cubic centimeter are more apt to lose strength than the so-called low-potency sera. A powdery deposit often forms in antitoxic sera after a time, but does not impair their value. Diphtheria antitoxin may be concentrated to some degree by precipitating, redissolving, and dialyzing.

The Concentration of Diphtheria Antitoxin.—Two chief methods of concentrating diphtheria antitoxin are in use in various laboratories. The first method is based on precipitation by means of ammonium sulfate, the second on precipitation by moderate

heat. The former method for precipitation of diphtheria antitoxin was worked out by Gibson.* The serum is precipitated by adding the same volume of a saturated solution of chemically pure ammonium sulfate. The precipitate formed is allowed to stand for about ten to twelve hours and then collected on large folded filters, preferably of hard paper. The precipitate is redissolved in a sufficient quantity of water to make up the volume of the original serum. After solution of the precipitate a quantity of saturated ammonium sulfate so.ution equal to the amount of water used for solution is added, and the precipitate which is formed collected in the same manner as the first precipitate. The precipitate is dried by pressure between mats of filter paper, and when of about the consistency of putty is dissolved in a saturated solution of sodium chlorid. The solution is filtered, and the filtrate, which contains the antitoxin, is precipitated by adding $2\frac{1}{2}$ c.c. acetic acid (80 per cent.) to each liter, and the precipitate collected on hard folded filters This precipitate is again dried between filter paper and then dialyzed in heavy parchment paper against running water until dissolved. After so ution the fluid is neutralized to litmus paper with a solution of Na_2CO_3, returned to the dialyzing bag, and dialyzed until the sodium chlorid has been practically removed.

The principle of this method of concentration is the separation of the pseudoglobulins which contain the antitoxic principle from the other constituents of the blood-serum. The precipitation with ammonium sulfate removes the albumins by leaving them in solution. The second precipitation is for the purpose of removing the remnants of albumin Saturated sodium chlorid solution dissolves the pseudoglobulin fraction, but not the other globulin fractions, so that the englobulin and fibrinoglobulin are removed by filtration. Acetic acid in small amounts precipitates the pseudoglobulins in saturated sodium chlorid solutions.

This method was improved by Banzhaf and Gibson,† who employed a fractional method of precipitation. The serum is first diluted with the same volume of water, and to this diluted serum

* Gibson: Jour. Biol. Chem., 1905, 1, p. 161.

† Banzhaf and Gibson: Jour. Biol. Chem., 1907, 3, 253.

is added half its volume of saturated ammonium sulfate solution. The precipitate which is formed is collected on hard folded filters, pressed nearly dry, and dissolved in saturated sodium chlorid solution, the solution being treated with acetic acid, and the resulting precipitate dialyzed in the same manner as the previous method. To the filtrate of the ammonium sulfate precipitate is added enough ammonium sulfate solution to bring the percentage up to about 38. The precipitate is then treated exactly like the previous one. To the remaining filtrate ammonium sulfate solution is added again until the saturation is 50 per cent. and the precipitate collected in the same manner. Three fractions of antitoxin globulins are obtained by this method. The last fraction contains the largest amount of antitoxin and may yield a concentration considerably higher than by the original method of Gibson. The first and second precipitates contain but small amounts of antitoxin.

An entirely new method of concentration was worked out by Banzhaf.* The serum is heated at 58° C. in a water-bath for about twenty-four hours. A heavy precipitate forms, consisting of albumins and some parts of the globulins which do not contain antitoxin. Some parts of the globulins seem to be changed by this heating process so as to become insoluble in saturated sodium chlorid solution, so that the true antitoxin globulins are left in solution in a very pure form after the heated serum has been saturated with sodium chlorid in powder form. This serum is then diluted with several times its volume of saturated sodium chlorid solution and, after having stood for several hours, is filtered. The clear filtrate is precipitated with acetic acid and the precipitate collected, pressed, and dialyzed in the usual manner. It is claimed that by this method a concentration of ten times the original potency can occasionally be obtained, while by the original Gibson method the concentration is two and a half to three times, and by the fractional method three to five times.

Concentrated sera have several advantages over native sera. The amount to be injected is smaller, an advantage of importance when large or frequent doses have to be given. Some of the super-

* Bull. of the New York City Antitoxin Laboratory, 1909.

fluous constituents of blood-serum are eliminated, constituents which may aid in the production of rashes or urticaria. One advantage is the greater yield made possible by the concentration, since with this method it is feasible to draw the blood from the horses into a solution of sodium citrate or, better, into a solution of potassium oxalate. Coagulation is prevented by the use of these chemicals, and a high yield of plasma can be obtained. The fibrinogen which remains dissolved in the oxalate plasma is precipitated with the first precipitate by the fractional method and by the heat in the last-mentioned method of concentration.

The globulin solutions after dialysis are filtered by suction through paper pulp in a Buchner funnel until perfectly clear, and then, after addition of 0.3 per cent. chloroform, are passed by suction or positive pressure (Fig. 10) through Berkefeld filters into sterile bottles.

The Curative Value of Diphtheria Antitoxin.—In order to cure a case of diphtheria in man, the horse-serum containing diphtheria antitoxin is injected with a sterilized syringe into the loose subcutaneous tissue, the best locality being in the back, near the angle of the scapula. If necessary, considerable quantities of the serum may be safely injected, but in serum sold in the United States at the present time the desired number of units is usually contained in less than 10 c.c. Subsequent doses may be given in other parts of the body and at intervals of a few hours if necessary. Administration of antitoxin by the mouth is valueless.* The amount of antitoxin given is fixed only by the exigencies of the case. In other words, the character of the symptoms and the stage of the disease must be the guide to the number of units injected. There has been a steady tendency to increase the dosage. At present 3000 or 4000 units are given as the initial dose in cases of moderate severity, and this dose is repeated at the end of every five to six hours until signs of improvement appear. In cases where an extensive membrane has already formed, 8000 to 10,000 units should be injected; in cases of great gravity, 50,000 to 100,000 units, in properly interspaced doses, have been given with remarkable success. There is no

* McClintock and King: Jour. Infect. Dis., 1906, 3, p. 701.

limit, as far as the antitoxin is concerned, to the number of units that may be safely injected.

Many attempts have been made to lessen the amount of fluid containing a given number of units. The use of a powerful toxin for immunization, the selection of horses that yield a particularly large number of antitoxin units per cubic centimeter, and improvements in methods of immunization and concentration have resulted in lowering considerably the dose of horse-serum. Serum containing 500 to 700 units per cubic centimeter is now commonly marketed, and a few horses have been known to yield serum of 1000 to 1500 unit strength. The so-called low-potency sera, however, containing about 300 to 500 units per cubic centimeter, are, unit for unit, just as efficacious, and can be produced much more economically, than the high-potency sera.

The administration of antitoxin is followed in some cases by temporary pain in the joints and by rashes. The rashes appear to be due to unknown substances in the horse-serum, which are present in larger amounts in some horses than in others. These substances may be present in the blood of a horse at one bleeding and absent at the next. They occur in both normal and immune animals. The concentrated serum contains, as a rule, less of these rash-producing substances than the original serum.

A few cases of sudden death have been reported following the administration of antitoxin serum.* The cause is unknown. It is possible that sensitization of the organism to horse-serum (see p. 164) is responsible, or that some obscure individual peculiarity lies at the bottom of the trouble. In comparison with the enormous number of antitoxin injections constantly made, such cases appear to be exceedingly rare.

The Results of Antitoxin Treatment.—The efficacy of antitoxin treatment is matter of common knowledge and the results need only be outlined here. The death-rate from diphtheria in certain large cities before and after antitoxin came into use (1894–95) illustrates the saving of life that has been effected.

* See, for example, Jour. Amer. Med. Assoc., 1908, 50, pp. 137, 456, and 468.

AVERAGE ANNUAL DEATH-RATE FROM DIPHTHERIA PER 10,000 POPULATION.

	1885–1894 Before Use of Antitoxin.	1895–1904 Antitoxin Period.
Paris	6.41	1.49
Berlin	9.93	2.95
Vienna	8.14	2.95
London	4.85	3.88
New York	15.19	6.62
Boston	11.76	6.34
Baltimore	7.34	4.99
Chicago*	14.29	5.13

Modes of Infection.—The source of infection is the human carrier of diphtheria bacilli. The ordinary way in which diphtheria is spread is by more or less direct transfer of bacilli from a mild case of the disease or from a convalescent patient, or from a well person that has come into contact with a case of diphtheria and harbors the specific germ in his throat or nose. It has already been pointed out that diphtheria bacilli may retain their virulence for a long time in particles of dried membrane. The germs have been found on children's toys, in the dust of sick-rooms, and clinging to the clothing of nurses. Under favorable conditions they may resist drying for several weeks. The chief danger, however, apparently does not depend upon dissemination of dust particles or upon inadequate disinfection of the surroundings of a patient, but rather upon the patient or convalescent himself. For many days, and exceptionally for months, after complete recovery the bacilli may persist in the throat and nose. Fully virulent germs have been found in a child's throat for as long as 335 days after the cessation of clinical manifestations. When diphtheria is prevalent in a school or an institution, bacilli are frequently found in a large percentage of the throats of perfectly healthy children. There is abundant evidence, therefore, that healthy individuals are sometimes the carriers of virulent diphtheria germs, and may be the means of causing serious epidemics. Chronic membranous rhinitis, due to the diphtheria bacillus, is not infrequently a source of infection.

It is well known that the disease is much more prevalent, as well as more fatal, among children than among adults. The effect of school attendance upon the spread of diphtheria has been clearly

* Antitoxin begun in 1895–96. Drop from 12.01 (1895) to 7.62 (1896).

shown by English health officials.* Not only has an increase in the prevalence of the disease in England been noticed coincident with the putting into operation of a compulsory education act (1870), but the number of cases of diphtheria reported has been observed to rise and fall in direct sequence to the occurrence of holidays and the resumption of school work. "The relation between school closure and diphtheria prevalence in Chelsea (Eng.) is shown in the following table, in which are set out the average number of cases occurring at all ages, and at the school age of three to thirteen years, in thirteen four-weekly periods, during the five non-epidemic years, 1890–1894 inclusive"†:

DIPHTHERIA IN CHELSEA.

Weeks.	Total Cases.	Cases at Ages Three to Thirteen.
1–4	**8.0**	**3.8**
5–8	11.4	4.8
9–12	10.8	5.2
13–16	11.4	5.6
17–20	13.6	5.6
21–24	11.8	5.4
25–28	16.4	7.4
29–32	14.8	8.2
33–36	**9.6**	**3.0**
37–40	14.2	7.0
41–44	13.8	7.8
45–48	21.2	11.8
49–52	15.0	8.8

The closure of the schools for the summer vacation (lasting a month), which usually commences in the thirtieth week of the year, is followed by a fall in the number of notified cases (thirty-third to thirty-sixth week). There is a corresponding fall after the Christmas holidays (first four weeks).

The use of the common drinking-cup and moistened lead-pencil, the friendly transfer of pocket-handkerchiefs, candy and chewing-gum, and the other familiar practices of school-children, afford opportunities for an immediate and tolerably direct passage of bacilli from an infected individual to a healthy one. It is probable, too, that in the act of coughing or talking droplets of moisture or mucus containing bacilli pass into the air and may be inhaled by

* Murphy: The Lancet, 1894, 2, pp. 1403–09.

† Parker: Trans. Epidemiol. Soc., Lond., 1896, N. S. 16, p. 240

bystanders. This is apparently, however, not the most usual mode of infection, which is generally by direct contact. There is no evidence that diphtheria bacilli are present in ordinary sewer air or that they ever effect an entrance to a dwelling through defective plumbing. It must be pointed out, however, that any condition, such as a damp or "raw" atmosphere, which tends to produce an irritated or weakened mucous membrane, is distinctly favorable to infection.

It is well established that diphtheria is sometimes disseminated by infected milk. Certain domestic pets, notably cats, have been regarded on epidemiologic evidence as being able to communicate the disease,* but further evidence on this point would be welcomed.

The so-called *avian diphtheria*, or "roup" of fowls and pigeons, has been frequently asserted to be due to the same micro-organism as that causing human diphtheria, but there are insurmountable objections to this view. The most important of these is the fact that the antitoxin which protects against the Klebs-Löffler bacillus is without effect upon the progress of roup. Moreover, the bacillus usually present in avian diphtheria has been isolated and differs in essential particulars from the Klebs-Löffler bacillus.

Prophylaxis.—In addition to the ordinary measures of quarantine and isolation, which, to be effective, should be based upon the systematic bacterial examination of the throat and nose of convalescents, a number of other methods have been suggested for checking the dissemination of the disease. It has been shown that diphtheria is primarily a disease of school-children and is largely affected by school attendance. An appreciation of this fact by the school authorities and the introduction of methods of examination and prompt isolation have led in some quarters to a material reduction of contagion. It should be clearly recognized that the disease is kept alive in the community and fresh outbreaks lighted up chiefly by infected individuals who mingle with their fellows. Experience has shown that the throats of persons coming in contact with a case of diphtheria are quite likely to harbor diphtheria bacilli, and that these persons, although themselves remaining well, may become centers for the further spread of this disease. The use of the antitoxic serum in doses of 500, or better 1000, units has been widely advocated as a prophylactic measure. A con-

* Cf. Thorne: "Diphtheria," London, 1891.

siderable degree of protection can be conferred in this way upon the children in a family where a case of diphtheria has appeared, and upon nurses or other attendants. Records of the Health Department of the City of Baltimore * show that only one case of diphtheria developed among three hundred and eighty-two children who, after more or less exposure, had been given 1000-unit doses. In certain European hospitals a preventive dose of antitoxin is given at regular intervals as a matter of routine to all children in the institution, and this procedure is said to be attended with great success. The passive immunity so obtained is relatively transient; it begins about twenty-four hours after the injection and is practically at an end after twenty-eight days.

Mixed Infections.—The Klebs-Löffler bacillus is found almost invariably associated in the false membrane with streptococci, staphylococci, or other micro-organisms. There is no doubt that these bacteria, especially the streptococci, often play an important part in both the local and general development of the infection. Certain common complications of diphtheria, particularly suppurative processes in the tissues of the neck, are unquestionably due to the action of the associated pyogenic organisms. Some observers have claimed that the virulence of the diphtheria bacilli is increased by symbiosis with the streptococci, but there is no convincing evidence in favor of this view. There have been a number of attempts to gage the influence of these mixed infections on the outcome of a diphtheritic attack. Simple streptococcus anginas are unquestionably of a more benign character than throat affections in which the Klebs-Löffler bacillus is found, either as the sole or predominant organism; but regarding the mixed infections of streptococci and diphtheria bacilli, opinions have been at variance. From analogies observed in animal experimentation, as well as on other grounds, there is reason to believe that the mixed infections, in which the streptococcus is actually sharing in the production of pathologic processes, are of a more serious character than those in which the Klebs-Löffler bacillus alone is the active factor.

Pseudo-diphtheria Bacilli.—Bacteria that closely resemble B. diphtheriæ but are non-virulent are not uncommonly encountered in the throats and noses of healthy individuals, in the con-

* Annual Report, 1904, p. 86.

junctival sac, and even in the false membrane in typical clinical diphtheria side by side with the true diphtheria bacillus. Löffler,* in 1887, reported finding an organism of this character in a diphtheritic membrane, and general attention was soon directed to the significance of the so-called pseudo-diphtheria bacilli by the similar observations of v. Hofmann-Wellenhof.† The organism often called by the name Hofmann's bacillus grows more luxuriantly upon agar than the Klebs-Löffler bacillus, is somewhat shorter and plumper, does not show granules when treated by the Neisser stain, and fails to produce acid in dextrose broth. It is, moreover, non-virulent for guinea-pigs. While it is relatively easy to separate typical pseudo-diphtheria bacilli possessing these qualities from B. diphtheriæ, considerable difficulty has arisen in attempting to apply in all cases a strict criterion of differentiation. Now and again bacilli

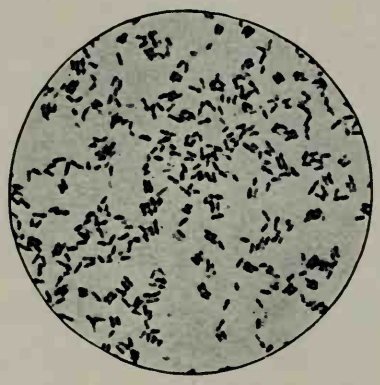


Fig. 61.—Pseudodiphtheria bacillus, methylene-blue; × 1000 (Park).

are found that resemble B. diphtheriæ in all important respects except in their lack of virulence, and by some authors these are classed as pseudo-diphtheria bacilli, although this is not in accordance with general usage. Such forms on closer study are often found to produce a small amount of toxin and are more properly regarded as attenuated forms. On the other hand, virulent bacilli have sometimes been found that do not ferment dextrose, but these also, owing to their specific toxin production, must be regarded as genuine examples of B. diphtheriæ. Neisser's stain is now generally admitted to be a far from absolute criterion. Avirulence is generally, although not invariably, associated with inability to ferment dextrose and with the absence of granules.

* Löffler: Centralbl. f. Bakt., 1887, 2, p. 105.

† Von Hofmann-Wellenhof: Wien. med. Wchnschr., 1888 38, pp. 65, 108.

There are not wanting statements by several observers to the effect that a transformation of one form into the other has been accomplished, and there are some who believe that the pseudo-diphtheria bacillus or the avirulent variety is simply a modified form of B. diphtheriæ, which has parted with its virulence and certain other properties under the stress of altered conditions. Statements by Lesieur,* for example, are especially specific on the question of transformation. It is claimed that virulent cultures of B. diphtheriæ have been transformed by the action of daylight into non-virulent ones exhibiting all the characters of the Hofmann bacillus, and, reciprocally, pseudo-diphtheritic bacilli have, by cultivation in collodion sacs within the bodies of rabbits, been transformed into organisms possessed of the qualities distinguishing B. diphtheriæ.

The alleged differences in the morphology of diphtheria and pseudo-diphtheria bacilli have already been touched upon, and, as has been stated, the occasional transformation of the granular into the solid-staining type is believed probable by several investigators. Careful cultivation experiments starting from a single cell are needed to prove to what extent the barred, solid, and granular types breed true.

From the public health point of view the question of the interrelation of the "real" and "pseudo" forms is of practical importance. It has been found that a considerable proportion of healthy persons in every community harbor the so-called pseudo-diphtheria bacilli (16 to 22 per cent.), but whether or not these persons constitute a menace to the health of the community is a question upon which opinions differ. The same investigations † show that about 1 or 2 per cent. of all persons harbor typical Klebs-Löffler bacilli (of the granular type), but that in this number only about 17 per cent. have virulent bacilli, "or, in other words, 17 in 5000 to 10,000 of all persons have diphtheria bacilli that are dangerous to the health." If it were true that the solid-staining, avirulent, pseudo-forms might suddenly, when transferred to a susceptible individual, acquire pathogenic power, the protection of the community by quarantine and isolation would present a different aspect. Further experi-

* Lesieur: Jour. de Physiol. et de Path. gén., 1901, 3, pp. 961, 1000.

† Jour. Mass. Assn. of Boards of Health, 1902, 12, p. 75.

mental study of well-defined diphtheria and pseudo-diphtheria bacilli is needed, especially in relation to virulence and variation.

In the light of our present knowledge the conclusion seems justified that there are at least two independent and distinct organisms, the diphtheria (Klebs-Löffler) bacillus and the pseudo-diphtheria (Hofmann's) bacillus. The true diphtheria bacillus is rarely found except in diphtheria patients (including latent cases of apparently simple "sore throat"), convalescents, and persons in contact with such cases. There does not seem to be adequate evidence of the transformation of the non-virulent pseudo-diphtheria bacilli into the true toxin-producing type.

Method of Diagnosis.—The examination of suspected throats for the diphtheria bacillus has been for years part of the routine work of several large and well-managed municipal laboratories in this country, and the methods employed after careful investigation have become well crystallized. Outfits for this work are issued to physicians on request. These consist, as a rule, of a tube of Löffler's serum, which should be freshly prepared, a tube containing one or more sterile swabs, and printed directions and record forms. The whole outfit is inclosed in a metal or pasteboard box. The swabs are usually composed of pledgelets of sterile cotton wound about the end of a wire or piece of wood. Some boards of health require that separate cultures be taken from the nose and throat when the examination is being made for the purpose of determining the end of a prescribed isolation period. Sometimes a cover-slip film is made at once from the swab, for immediate microscopic examination, but this procedure, although it sometimes facilitates a speedy diagnosis, will often give a negative result if bacilli are present in small numbers. The method of cultivation is much more reliable. After the swab has been rubbed carefully over the serum, the tube is incubated at 37° C. until the next morning, when cover-slip films are made from the growth on the medium and examined microscopically in the usual way. A single negative result or even more cannot be taken as conclusive proof that diphtheria bacillus were actually absent in the throat at the time the swab was used, since if only a few bacilli are present, or if they are in relatively inaccessible locations, as in laryngeal cases, they might easily be missed. Many boards of health require two successive negative cultures for release from quarantine.

CHAPTER XVI

THE GROUP OF COLON-TYPHOID BACILLI

One of the most important groups of pathogenic bacilli is that which includes the typhoid bacillus, the bacillus of hog-cholera, certain bacilli found in cases of meat-poisoning, and other related organisms. The group is a large one and comprises many varieties that are as yet imperfectly separated from one another. Great advances, however, have been made in differentiation within this group in the last few years.

Characteristics and Subdivisions of the Group.—Under favorable conditions of growth the prevailing form is a plump, straight rod with rounded ends. Short, oval forms are not uncommon upon certain media, and long filamentous forms are occasionally developed, especially at high temperatures. The cell protoplasm often stains irregularly, when carbol-fuchsin is used. The bacilli lose the stain when treated by Gram's method. No spores are known to be formed by any of this group.

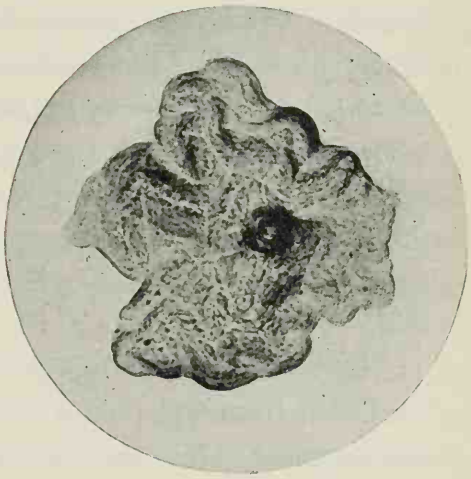


Fig. 62.—Bacillus typhosus colony on gelatin, seventy-two hours old; unstained; Neufeld prep. (Kolle and Wassermann).

One of the distinguishing cultural characteristics of these organisms is their mode of growth upon the surface of gelatin. This feature is well seen in colonies upon a gelatin plate. Upon the surface of the medium an irregular, thin, notched, leaf-like expansion is formed, which is so typically produced by members of the group that the term "colon-like" or "typhoid-like" has been applied to this kind of colony (Fig. 62). This constitutes one of the more constant distinguishing growth characters of the

group, although B. [lactis] aerogenes, an organism in most respects closely related to the colon bacillus, develops colonies that are projecting, have rounded margins, and depart materially from the type. In no case is gelatin liquefied. All the organisms of this group are able to reduce nitrate to nitrite in the presence of organic matter, and the majority of strains are able also to reduce nitrite with evolution of nitrogen.

A particularly interesting biologic character of the group is that many of the members appear to be on the verge of parasitism, and, as it were, stand ready to assume a parasitic mode of life when a favorable opportunity presents itself. Many varieties, such as the forms found in the intestines of certain of the higher animals, occupy a position intermediate between saprophytes and parasites, and from this point of view the group is at present in a state of unstable biologic equilibrium and must be looked upon as possessing marked potentialities for evolution in the direction of parasitism.

Three subdivisions of the group can at present be distinguished:

1. B. coli; the capsulated bacteria.

2. The B. enteritidis group, including B. choleræ-suis, B. icteroides, B. psittacosis, and various "paracolon" and "paratyphoid" bacilli.

3. B. typhosus and B. dysenteriæ; B. fecalis alkaligenes.

Some of the main points of difference between the several subdivisions are shown in the following comparison:

1. *B. coli:* Motility is not pronounced in most cultures; often only a few individuals in the field show independent movement; few flagella. Dextrose and lactose are fermented with gas-production, some varieties fermenting saccharose also Milk is curdled, usually within forty-eight hours, at 37°, with abundant acid production. Luxuriant growth on potato, usually with a brown tinge. Indol is produced by most varieties in large amount. Under most conditions not pathogenic for man or the lower animals. When injected intraperitoneally into rabbits and guinea-pigs a fatal result usually ensues, but considerable variation in virulence is shown by different strains.

2. *B. enteritidis:* Actively motile; 10 to 14 flagella. Dextrose is fermented with gas-production, but no gas or acid is formed from lactose. Milk is never curdled; on prolonged cultivation under aërobic conditions the milk acquires a slight primary acidity, then becomes strongly alkaline, and finally the casein is dissolved. Indol is produced not at all or very scantily. Distinctly pathogenic for many of the lower animals and for man.

3. *B. typhosus:* The typhoid bacillus is actively motile and possesses 10 to 14 flagella. B. dysenteriæ, otherwise closely related, is slightly motile or devoid of motility, according to some observers. Dextrose is fermented with production of acid, but gas is never produced; no acid is produced from lactose. Milk is never curdled, although a slight initial acidity develops, followed by a return to the original reaction; an alkaline reaction is produced in milk by some strains, but not to such an extent as in the preceding group. No indol is formed under ordinary conditions of cultivation. Pathogenic for man, less so for the lower animals.

Subdivision 1

Bacillus coli

The organism taken as the type of this class was described under the name of Bacterium coli commune by Escherich in 1886.* The original culture was isolated from the dejecta of a breast-fed infant, and cultures from this source are still considered by Escherich to be especially typical. Other bacteria which were discovered about the same time and variously designated, such as the "Naples cholera germ," or B. neapolitanus, † isolated by Emmerich ‡ from the dejecta of patients suffering from Asiatic cholera, should doubtless rank as members of this class. The typical Bacillus coli is widely distributed in nature and has been isolated from air, from water, and from soil. In only a limited sense, however, is it "ubiquitous." It is found by far most abundantly and constantly in the intestinal tract of man and many of the higher animals. In the colon it occurs in especial abundance, and is so characteristic an inhabitant of this region of the intestine as fully to deserve the name that has been bestowed upon it. From fresh, healthy human feces it is often isolated in pure culture by the ordinary aërobic methods, although microscopic examination shows that other kinds of microorganisms are also present in the feces. The varieties of B. coli that are isolated from the intestinal contents of different species of mammals differ slightly in their biologic characters. Moore,§ for example, has shown that cultures of B. coli obtained from the intestines of the dog are more virulent, when injected intraperitoneally into guinea-pigs, than those from the intestine of the rabbit or guinea-pig.

Morphology.—The morphology of the colon bacillus exhibits considerable variation. The ordinary dimensions in stained preparations from cultures upon nutrient agar or gelatin range from 2 μ to 4 μ in length and from 0.4 μ to 0.7 μ in breadth (Fig.

* Escherich: Die Darmbacterien des Säuglings, Stuttgart, 1886.

† According to a strict application of the rules of priority, the bacillus now known as B. coli should be called B. neapolitanus.

‡ Emmerich: Arch. f. Hyg., 1885, 3, p. 291.

§ Moore: Amer. Med., 1902, 3, p. 504.

63). Very short, oval and coccus-like forms are encountered not infrequently, and usually predominate when the bacillus is observed directly in normal animal tissues.

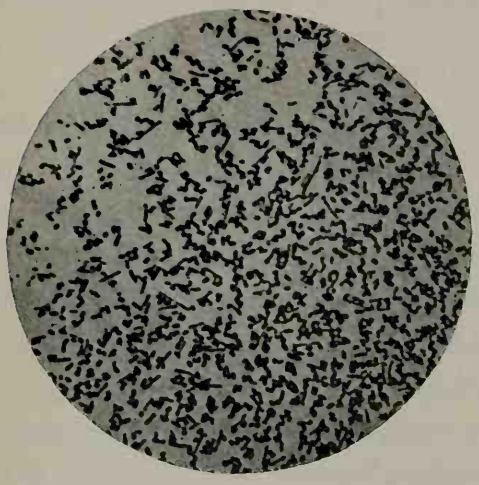


Fig. 63.—Bacillus coli; twenty-four-hour agar culture; × 650 (Heim).

The most typical members of this group possess motility; flagella can be demonstrated by appropriate stains (Fig. 64).

Cultural Characteristics.—The more salient biologic characters of this subdivision of the colon-typhoid group have already been noted in tabular form. Gelatin is not liquefied; milk is curdled with acid reaction, usually within forty-eight hours, by the cultures that must be regarded as the more typical or more vigorous. Indol is produced in abundance by all vigorous strains. Dextrose is fermented, with the production of gas, the gas being mainly carbon dioxid and hydrogen in the approximate proportion of two parts of H_2 to one of CO_2. Lactose also is always fermented with gas-production, the ratio of hydrogen and carbon dioxid being, however, somewhat less constant than in the dextrose fermentation.

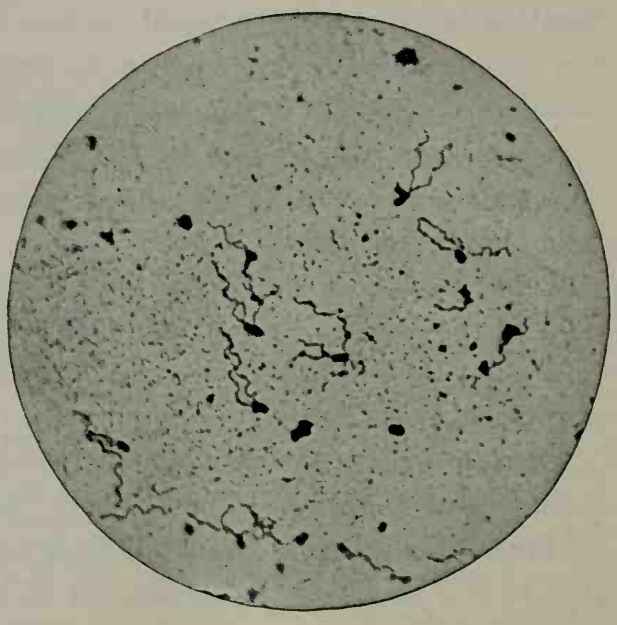


Fig. 64.—Bacillus coli with flagella stained by van Ermengem's method; × 1000 (Williams).

Nearly one-half of the colon bacilli that are isolated from various sources produce gas in saccharose broth; they are not known

to differ in other characters from those unable to ferment saccharose.*

Certain bacilli not infrequently isolated from water, soil, and other sources, are regarded by many investigators as weakened or aberrant members of the colon group. They depart from the so-called type in several more or less significant respects. A not uncommon divergence consists in the inability to generate any considerable quantity of acid in milk, so that the milk is not curdled promptly (*i. e.*, within forty-eight hours at 37°), or in some cases not at all. Ability to produce indol in peptone solution is likewise lacking in some cultures otherwise typical. Certain of these bacilli are obviously attenuated forms of B. coli, and may be made to approximate closely to the type by the method of rejuvenation or broth cultivation elsewhere described (p. 51). A few observers would include in the colon group somewhat similar organisms that are unable to produce gas in dextrose broth, although in other respects possessing the biologic characters of the type, but it is not generally considered that forms devoid of this fermentive power should be classed as colon bacilli. When the colon bacillus is introduced into the bodies of various animals, it is able to bring about certain morbid changes, as was shown by Emmerich in his study of "B. neapolitanus," and has been confirmed since by many workers. Intraperitoneal injection of 2 c.c. of a twenty-four- to forty-eight-hour-old broth culture usually proves fatal to a guinea-pig within three days. Cultures isolated from various tissue lesions and suppurative processes are more virulent for animals than those isolated from the normal intestine. Subcutaneous inoculation is much less likely to result fatally than intraperitoneal. Some writers assert that cultures of B. coli isolated from the contents of a diseased intestine are more virulent than those from a normal individual, but investigators are not in accord on this point.

Pathogenesis.—As regards pathogenicity for man, the common occurrence of agonal or post-mortem invasion of the body by the colon bacillus tends to diminish the value of the supposed evidence derived from finding the colon bacillus in the internal organs after death, and there can be no doubt that the rôle in human pathology assigned to the colon bacillus by some investigators, notably certain

* Jour. of Hyg., 1903, 3, p. 1.

French bacteriologists, has been greatly exaggerated. Failure to distinguish between the true colon group and the group of meat-poisoning bacilli is doubtless responsible for some of the statements attributing pronounced pathogenic properties to B. coli. The frequent ascription of various inflammatory processes, particularly those occurring in the appendix and peritoneum, to the unaided activities of B. coli appears to be without sufficient justification. Many of the cases reported rest on the evidence derived from simple aërobic cultivation, and the possible concurrence of anaërobes or other organisms not growing by ordinary methods has not been excluded.

It is well established, however, that under some conditions the colon bacillus is able to pass from the digestive tract into the blood, whence it may invade the gall-bladder and bile-ducts and cause cholangitis and cholecystitis. Convincing evidence on this score has been obtained both from human pathology and from animal experiment. The bacillus is often found in the core of gall-stones. Kramer * has made the interesting observation that in cultures the colon bacillus (and the typhoid bacillus) can precipitate cholesterin and other biliary constituents and hence may take an important part in gall-stone formation. B. coli is also able to produce lesions of the urinary passages, and the majority of all cases of cystitis are to be laid at the door of this organism. According to some writers (Rostoski †), as high as 80 per cent. of all cases of urinary tract infection are caused by the colon bacillus. Animal experimentation and the agglutination test support the clinical and pathologic findings in these cases of urinary tract infection. In many cases infection of the bladder appears to take place by way of the urethra rather than through the kidneys from the blood-stream.‡ In some suppurative processes, as in the infection of wounds, B. coli has been recognized as the active agent, and while its share in pyogenic processes is not great, its occasional participation is undoubted.

The pathogenic properties of the colon bacillus when confined within the human intestine are not pronounced under ordinary con-

* Kramer: Jour. Exper. Med., 1907, 9, p. 319.

† Rostoski: Deut. med. Wchnschr., 1898, 24, p. 235.

‡ Bond: Brit. Med. Jour., 1907, 2, p. 1639.

ditions of life. Practically all healthy individuals appear to harbor this organism in their intestinal contents. Excessive sugar fermentation by B. coli with liberation of irritant acids and gas may be responsible for some cases of diarrhea, but it is not clear that there is any concomitant increase of ability to invade the tissues among the bacilli that take part in this process. Colon bacilli of human origin are practically devoid of power to dissolve and peptonize native proteids such as casein and egg-albumen. It is therefore only in the presence of putrefactive anaërobes or other bacteria capable of peptonizing proteids that colon bacilli aid in excessive intestinal putrefaction.*

THE CAPSULATED BACILLI

A large group of bacilli that are non-motile and heavily capsulated, but which in other respects closely resemble the colon bacillus, is often considered as a separate class of bacteria, but for various reasons is here included in the same general subdivision with the colon bacillus. Great differences and variations are shown in fermentive power by the different members of this group, and several observers have established subdivisions of the group on the basis of this characteristic.† Pathogenicity is likewise a very variable quantity.

The organism often found in sour milk, and known as **Bacillus [lactis] aerogenes,** bears many points of resemblance to B. coli, and is often found associated with it in the intestine and elsewhere. In general the fermentive power of B. aerogenes is somewhat greater than that of B. coli. Milk is usually curdled more rapidly, and gas is formed from potato starch. Growth in gelatin is more luxuriant; in gelatin tubes a projecting "nail-head" growth is characteristically produced. Indol is usually produced in peptone solution. Capsule formation occurs in milk cultures. B. aerogenes is commonly present in abundance in souring milk.

The most familiar of the pathogenic capsulated bacilli is the form known as Friedländer's pneumobacillus or **Bacillus pneumoniæ** (Fig. 65). In the early studies upon the bacteriology of

* Herter: "The Common Bacterial Infections of the Digestive Tract," New York, 1907, p. 155.

† See, for example, Perkins: Jour. Infect. Dis., 1904, 1, p. 241

pneumonia this organism was considered to bear an important relation to the disease, but further investigation has tended to show that although frequently present in pneumonia as a secondary invader, it is very rarely the sole and primary cause. In general morphology and in capsular formation it sometimes resembles the pneumococcus, but is easily distinguished from it by its ready growth upon the ordinary artificial media and by the fact that it loses the stain when treated by Gram's method. The pneumobacillus has been found in suppurative processes in various parts of the body and in some few cases of generalized infection. It is pathogenic for mice and guinea-pigs. The bacillus known as **B. [mucosus] capsulatus** is very similar to, and in the opinion of some observers identical with, Friedländer's bacillus. Some writers prefer to designate the whole group as the "*Mucosus Capsulatus* group."

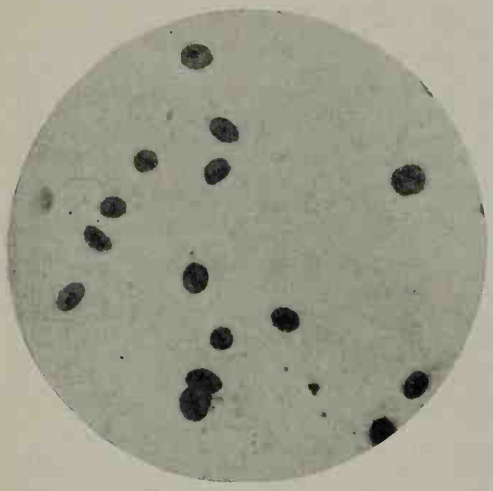


Fig. 65.—Friedländer's pneumobacillus. Welch's capsule stain; × 1100.

Organisms of this group have been found in a variety of pathologic conditions. Howard* and others have reported cases of hemorrhagic septicemia in man due to capsulated bacilli. A bacillus found in a catarrhal condition of the nose known as ozena (**B. ozenæ**, Abel †) belongs to the group of capsulated bacilli (Fig. 66), and a similar capsulated organism has been found in a not very common disease of the upper respiratory tract termed rhinoscleroma. The lesions in rhinoscleroma are of the infectious granuloma type, and a rather characteristic bacillus has been described as occurring quite uniformly in a state of purity deep within the tissue lesions. The "bacillus of rhinoscleroma" is unable, as a rule, to produce gas in any carbohydrate media, and is only feebly pathogenic for the laboratory animals. Some investigators

* Howard: Jour. of Exper. Med., 1899, 4, p. 149.

† Abel: Zeitschr. f. Hyg., 1896, 21, p. 89.

look upon the bacilli found in ozena and rhinoscleroma as secondary invaders and as identical with Friedländer's pneumobacillus. Though this is an extreme view, the etiologic relation of these organisms to the affections with which they are associated is not certainly established. By use of the precipitin method, however, v. Eisler and Porges * have succeeded in differentiating the bacilli of ozena and rhinoscleroma from the pneumobacillus.

Morphologically similar to B. coli are the anaërobic bacteria designated as **B. bifidus** (Tissier) and **B. acidophilus** (Moro). Unlike the colon bacillus, however, both these bacilli are gram-positive. According to a number of observers, they are the predominant organisms in the digestive tract of healthy human infants. B. bifidus owes its name to a true division or bifurcation of one or both ends of the cell. It is, however, quite polymorphous, and a number of varieties are recognized by students of the intestinal flora.† Pure cultures are somewhat difficult to obtain, as B. coli and other associated organisms are likely to overgrow the slow-growing B. bifidus. B. acidophilus is an anaërobic bacillus closely related to B. bifidus, but which develops readily on a strongly acid medium. The systematic position of these microorganisms is uncertain, and they are mentioned in connection with the colon bacillus simply for convenience.

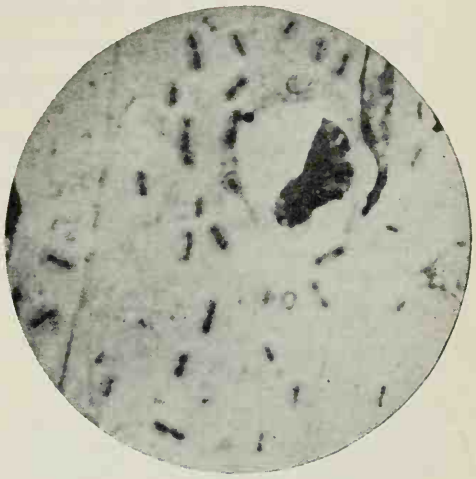


Fig. 66.—Bacillus ozenæ in nasal secretion; methylene-azure; Zettnow prep. (Kolle and Wassermann).

* Von Eisler and Porges: Centralbl. f. Bakt., Orig., 1906, 42, p. 660.

† Herter: "Bacterial Infections of the Digestive Tract," pp. 41–45.

CHAPTER XVII

THE GROUP OF COLON-TYPHOID BACILLI (Continued)

Subdivision 2

The Bacillus Enteritidis Group

Bacillus Enteritidis.—Under this head may be included certain bacilli isolated from various meat-poisoning epidemics on the continent of Europe and in England. The organism known in laboratories as *Gärtner's bacillus* is typical of the class. It was found by Gärtner (1888)* under the following circumstances: The flesh of a diseased cow which was sold for food in a village in Saxony was partaken of by a number of persons, fifty-seven of whom became ill. One young man consumed 800 grams of raw meat and died in about thirty-five hours. From the organs of this fatal case Gärtner isolated a micro-organism which he called B. enteritidis (Fig. 67); the same organism was obtained also from the flesh of the diseased cow. Similar bacteria have been encountered in a case of meat-poisoning in Brussels and in other outbreaks in Germany. The biologic characters of B. enteritidis and its varieties correspond very closely with those of the so-called hog-cholera bacillus.

Fig. 67.—Bacillus enteritidis, Gärtner; pure culture; van Ermengem prep. (Kolle and Wassermann).

B. choleræ-suis.—The bacillus of hog-cholera was discovered in 1885 by Salmon and Smith.† Some confusion in nomenclature at first arose from the fact that the organism now known as B. choleræ-suis was unfortunately first described as "the bacterium of swine plague." The name of swine plague

* Gärtner: Korresp. d. allg. ärztl. Vereins. von Thüringen, 1888, 17, p. 233

† Salmon and Smith: Centralbl. f. Bakt., 1891, 9, p. 253.

has been since limited to another disease of swine, differing from hog-cholera both in its morbid anatomy and as regards the biologic characters of the specific organism associated with it. Owing to the similarity between the symptoms of hog-cholera and those of swine plague (German, *Schweineseuche*), the differential diagnosis of these two diseases can often be made only upon the basis of the bacteriologic findings. The more important differences between the two species of microbes are shown by the following comparison, which the confusion that has crept into the literature of the subject seems to render necessary.

1. **Bacillus of Hog-Cholera.**—Actively motile, with from three to nine flagella. Vigorous growth in nutrient broth and moderate growth on potato. Renders milk at first slightly acid, then strongly alkaline, and dissolves the casein. Ferments dextrose with gas-production. Pigs that have fasted for twenty-four hours, when fed with cultures, develop extensive intestinal lesions which result fatally.

2. **Bacillus of Swine Plague.**—Belongs to the hemorrhagic septicemia group. Non-motile. No flagella demonstrated. Growth in nutrient broth moderate or feeble. No growth on potato. Acid is generally produced in milk, but not in sufficient quantity to cause coagulation. Acid is produced in dextrose broth, but no gas. Cultures fed to pigs usually produce no effect.

True hog-cholera is widely disseminated throughout the central United States and also prevails in Great Britain and on the continent of Europe. An acute and a chronic form have been reported, the latter being apparently the more common. Although the micro-organism known as the hog-cholera bacillus is found in some epidemics of hog-cholera, doubt has been thrown upon its causal relation to the disease by the fact that it is not found in all cases, and especially by the discovery that the disease can be transmitted to healthy animals by inoculation with diseased body-fluids filtered through the finest porcelain filters.* Since the disease can be caused by a filterable virus, the so-called hog-cholera bacillus must be considered to have a very subordinate rôle, if any, in this infection.†

Paracolon and Paratyphoid Bacilli.—Achard and Bensaude ‡ were the first to discover an atypical organism in a typhoid-like disease of man. Later Gwyn § reported a case which apparently presented all the clinical symptoms of typhoid fever, but in which the serum reaction for the typhoid bacillus was lacking. From the blood Gwyn isolated a bacillus closely akin to B. choleræ-suis and B. enteritidis, which agglutinated with the patient's serum.

* DeSchweinitz and Dorset: Bureau of Animal Industry, 1903, Circular 41; Boxmeyer: Jour. Infect. Dis., 1905, 2, p. 359.

† See especially "The Etiology of Hog-Cholera," Dorset, Bolton and McBryde, Bureau of Animal Industry, Bull. No. 72, 1905.

‡ Achard and Bensaude: Soc. méd. des Hôp. de Paris, 1896, 3d S., 13, p. 679.

§ Gwyn: Johns Hopkins Hosp. Bull., 1898, 9, p. 54.

Since that time a number of investigators * in different parts of the world have isolated similar organisms from the blood of patients suffering from a disease that, so far as clinical symptoms are concerned, is sometimes substantially identical with typhoid fever. Many cases of "paracolon" or "paratyphoid" infection show a tendency to run a rather mild course and, according to Lentz,§ are marked by a sudden onset with chills, but are otherwise very similar to infections with the true typhoid bacillus. A certain proportion of the negative results reported with the agglutination test in apparent typhoid fever can be plausibly accounted for by the supposition that a paratyphoid rather than a typhoid bacillus was the exciting cause of the attack. Many isolated cases of paratyphoid infection have been observed, and one small epidemic due to water infection has been attributed to an organism of this group.† It is not yet known what proportion of cases clinically resembling typhoid fever are due to paratyphoid bacilli. In a series of thirty cases studied by Ruediger ‡ in Chicago, paratyphoid organisms were isolated from the blood in two cases, typhoid bacilli in seventeen cases. Some cases of paratyphoid infection are accompanied with severe diarrhea and resemble the so-called cholera nostras. The observations of Hetsch § indicate that they might be mistaken clinically for Asiatic cholera.

The pathologic anatomy of paratyphoid fever is not very fully known, since, owing to the relatively low mortality, few thorough autopsies have been made. Up to the present the findings indicate that the lymphatic system is not as generally involved as in typhoid fever; this is especially evidenced by the absence of the characteristic typhoid ulcerations of the Peyer's patches. Broadly speaking, the lesions of paratyphoid infection are those of a severe gastroenteritis.

Two varieties of paratyphoid bacilli are recognized, usually designated as type **A** and type **B.** Type **B** is probably the more widely distributed, and is found in by far the greater number of cases of paratyphoid fever. According to some investi-

* Schottmüller: Ztschr. f. Hyg., 1901, 36, p. 368; Buxton: Journ. Med. Res., 1902, 8, p. 201.

† See Jürgens: Ztschr. f. Hyg., 1903, 43, p. 372.

‡ Ruediger: Trans. Chicago Path. Soc., 1903, 5, p. 187.

§ Hetsch: Klin. Jahrb., 1907, 16, p. 267.

gators,* B. paratyphosus **B** is identical with B. enteritidis, type Aertryck (not type Gärtner), and the bacillus of mouse typhoid. The presence of common agglutinins, however, renders the tracing of relationships within this group particularly hazardous. Type **A** stands nearer to the typhoid bacillus than type **B**, as is especially manifested by its behavior in milk cultures, where it does not produce alkali and leaves the casein undissolved. The specific agglutinins and other antibodies produced by the two types of paratyphoid bacilli are different. The cases of illness in which type **A** is found resemble typhoid fever. The pathogenicity of type **A** for the lower animals is less than that of type **B** and corresponds more nearly to that of the typhoid bacillus.

Epidemiologically paratyphoid fever appears to be frequently due to food poisoning. Milk and meat probably play quite a part in infection, while water is thought to be sometimes implicated. The fact that both typhoid and paratyphoid fever may be caused by polluted water, and that cases may exist side by side in the same epidemic undifferentiated, suggests that the full extent of water-infection may not now be recognized.

Paratyphoid bacilli are widely distributed in nature. They are found not infrequently in the healthy human intestine, and occur often also in the intestine of swine, mice, and other animals. They appear sometimes to be the exciting cause of udder inflammations in cattle, and may perhaps be conveyed to man through the medium of milk from udder-sick cows.

No connection of paratyphoid fever with specific diseases of the lower animals has been certainly established. In spite of the extraordinarily close resemblance between B. paratyphosus, B. choleræsuis, B. psittacosis, and the bacillus of mouse typhoid (B. typhi murium), extending even to agglutinating and immunizing tests, a difference in pathogenicity seems to exist, and reciprocal infections of the domestic animals and man are, to say the least, very rare. Shibayama,† however, has reported a number of instances in which cakes containing mouse-typhoid bacilli were eaten by mistake and severe gastro-enteritis ensued.

The existence of a violent gastro-intestinal form of paratyphoid

* Kutscher and Meinicke: Ztschr. f. Hyg., 1906, 52, p. 301.

† Shibayama: Münch. med. Wchnschr., 1907, 54, p. 979.

fever and a milder typhoid-like form, especially in the meat-poisoning cases, may possibly be explained by supposing that a simple infection occurs in the latter case, while in the more severe and sudden form intoxication from the ingestion of formed poison is mainly responsible. The resistance of the paratyphoid poison to heat is a fact in favor of this explanation.

A number of other organisms of more or less bacteriologic importance belong to the B. enteritidis group. B. icteroides (Sanarelli), believed by the discoverer to be the cause of yellow fever, and B. psittacosis, are two of the better known forms. **B. psittacosis** was found in a highly fatal, pneumonia-like disease of human beings which broke out in Paris in 1892, causing forty-nine cases and sixteen deaths. It was shown that sick parrots from South America were the starting-point of this outbreak. Other cases of this peculiar infection, in some instances likewise communicated by parrots, have been recorded by Leichtenstern* in Cologne and by other observers.†

Much interest attaches to the interrelationship of the bacilli composing the hog-cholera group, and attempts have been made to utilize the agglutination test in disentangling the biologic affinities. The results of some observers (Durham,‡ de Nobele, Buxton§) suggest a grouping into at least two divisions: (1) those bacteria more or less closely connected with the domestic animals, including the hog-cholera bacillus and the bacilli found in certain meat-poisoning epidemics; (2) those more or less closely related to typhoidal human infections, such as the so-called paratyphoid organisms, together with some bacilli of the B. enteritidis type. The agglutinative and other affinities of the members of this group, however, call for further study.

* Leichtenstern: Centralbl. f. allg. Gesundh., 1899, 18, p. 241.

† Vickery: Med. News, 1904, 85, p. 780.

‡ Durham: Jour. Exper. Med., 1901, 5, p. 353.

§ Buxton: Jour. Med. Res., 1902, 8, p. 201.

CHAPTER XVIII

THE GROUP OF COLON-TYPHOID BACILLI (Continued)

Subdivision 3

The Typhoid-Dysentery Group

THE TYPHOID BACILLUS (B. TYPHOSUS)

The typhoid bacillus was discovered by Eberth in 1880 * in the mesenteric glands and the spleen of persons dying from typhoid fever. With the microscope the bacilli are usually seen in stained sections of the spleen or liver, where they occur in groups or masses rather sharply focalized, scattered individuals not being often found. In 1884 Gaffky † succeeded in growing Eberth's bacillus upon culture-media, and since that time evidence has slowly accumulated that this organism is the cause of typhoid fever.

At first difficulties stood in the way of the general acceptance of this view. Eberth's bacillus proved pathogenic for the lower animals when injected intraperitoneally or intravenously, but it was not possible to produce typhoid fever in animals by feeding them with small numbers of bacilli, the natural mode of infection in man, nor was it possible by any mode of infection to reproduce the gross lesions of human typhoid fever. Strong evidence of causal relationship, on the other hand, was brought out in the discovery of "Pfeiffer's phenomenon" (p. 143) and in the "Gruber-Widal test" or agglutination reaction. Thoroughly characteristic typhoidal lesions are said to have been produced in the chimpanzee by feeding with typhoid bacilli,‡ and pure cultures of the Eberth-Gaffky bacillus swallowed with suicidal intent have given rise to typhoid fever in man (Duflocq and Voisin §).

Characteristics of the Typhoid Bacillus.—The typhoid

* Eberth: Archiv. f. path. Anat., 1881, 83, p. 486.

† Gaffky: Mitt. a. d. kais. Gesund., 1884, 2, p. 372.

‡ Grünbaum: Brit. Med. Jour., 1904, 1, p. 817.

§ Duflocq and Voisin: Arch. gén. de méd., 1903, 2, p. 2197.

bacillus is a short, plump rod, its dimensions ranging, as a rule, from 1 μ to 3 μ in length and from 0.5 μ to 0.8 μ in breadth (Figs. 68 and 69). It is actively motile and does not retain the stain when treated by Gram's method. The cell inclusions at one time mistaken for spores by Gaffky and others were probably either vacuoles or metachromatic granules. As regards growth upon media, it may be said that, as a rule, the typhoid bacillus is able to grow far less luxuriantly than the colon bacillus, and the chemical changes that it is able to effect are much less numerous and profound than those that are brought about by the latter organism. Consequently, the cultural characteristics of the typhoid bacillus are distinctly negative as compared with the positive character of other members of the group; in peptone solution no indol is produced; in dextrose broth and agar, acid is produced but no gas is formed (Fig. 71); no acid is produced from lactose and saccharose; milk is not curdled, and although some strains produce a small amount of alkali in milk and in litmus whey, the change in reaction is seldom, if ever, as great as that produced by most of the members of the B. enteritidis or hog

Fig. 68. — Bacillus typhosus, twenty-four-hour agar culture; × 650 (Heim).

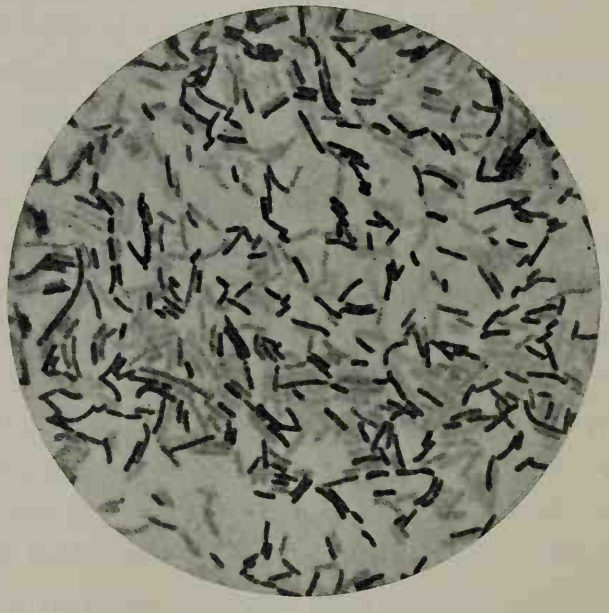


Fig. 69.—Bacillus typhosus. Impression preparation from gelatin plate. Fuchsin; × 1000.

cholera group. The colonies upon gelatin are thin, bluish-white expansions with irregularly notched margins, and are, as a rule, not as large or thick as the colonies of the colon bacillus (Fig. 72). Typical cultures of the typhoid bacillus grow upon the surface of acid potato, but the growth is thin, moist and colorless, and forms the so-called invisible film, which is strikingly unlike the profuse brownish growth of the typical colon bacillus. On pieces of potato with an alkaline reaction, the growth is more like that of the colon bacillus. No final diagnostic value at present attaches to the growth upon potato, owing to the wide variations both in the reaction of potatoes and in the behavior of different strains of bacilli, but nevertheless the growth on potato is often of determinative importance, and on acid potato typical cultures of typhoid bacillus and colon bacillus can be readily distinguished. A similar distinction appears upon Heinemann's substitute for potato.*

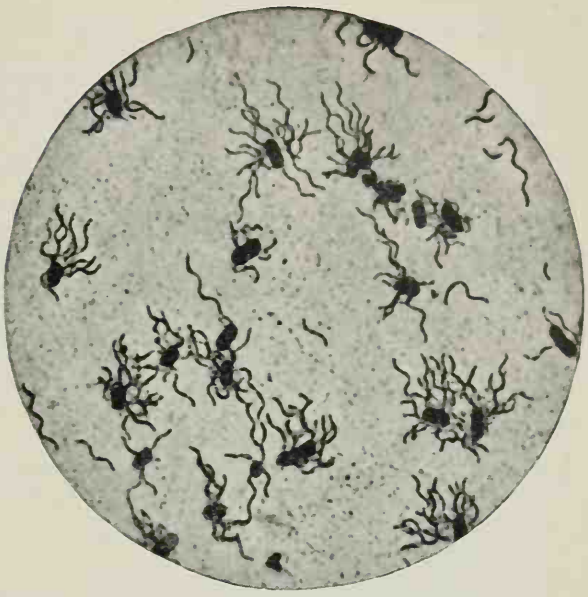


Fig. 70.—Bacillus typhosus, from an agar culture six hours old, showing the flagella stained by Löffler's method; × 1000 (Fränkel and Pfeiffer).

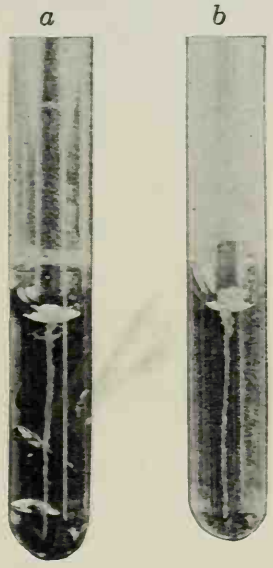
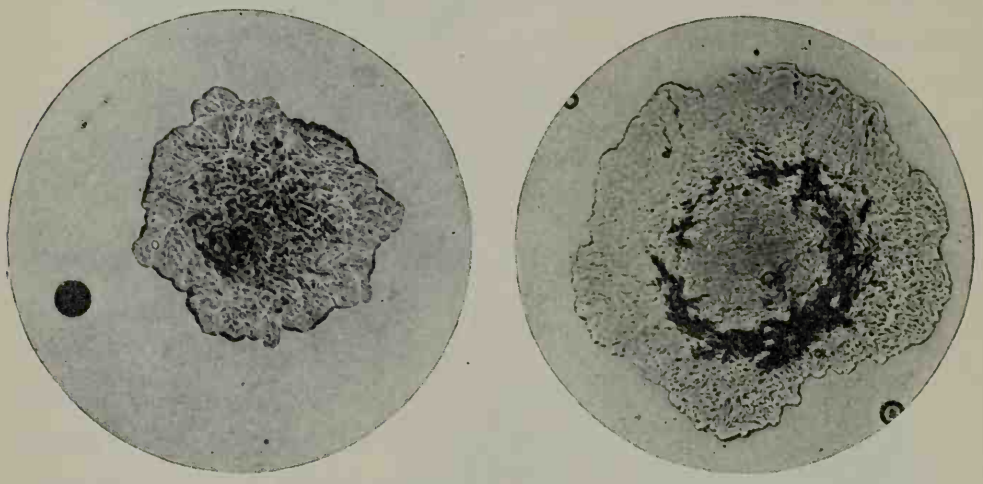


Fig. 71.—*a*, Bacillus coli in dextrose agar, showing gas bubbles; *b*, Bacillus typhosus.

The more salient points of difference between the typhoid bacillus and the other organisms of the group have been already presented in tabular form (p. 254). Since the various bacilli belonging to the colon-

* Heinemann: Jour. Infect. Dis., 1907, 4, p. 282.

typhoid group are in many respects similar, and are frequently found side by side in infected organs, in polluted water, and elsewhere, the application of elaborate and extended comparative tests is requisite for a sure diagnosis. Much ingenuity has been expended in devising new methods for isolation and identification, but it is now generally admitted that any satisfactory identification of the typhoid bacillus through a single test is impossible, and that only a comprehensive study of a considerable number of biologic attributes enables an identification to be made with a reasonable degree of certainty. The advance of bacteriologic investigation in this field has been accompanied by a steady



A B

Fig. 72.—Gelatin colonies two days old of (A) bacillus typhosus, and (B) bacillus coli; × 21 (Heim).

increase in the number of tests that must be applied in order to arrive at a satisfactory identification of the specific organism of typhoid fever.

Methods for Isolating the Typhoid Bacillus.—A large number of methods have been proposed to facilitate the speedy isolation of the typhoid bacillus from polluted water, fecal discharges, and other suspected sources. One of the chief difficulties that these methods seek to overcome is the separation of the typhoid bacillus from the colon bacillus and allied varieties. The problem consequently resolves itself into the discovery of a medium which shall both favor the development of the typhoid bacillus, and also assist in differentiation between B. typhosus and B. coli. It

has proved a relatively simple matter to suppress the common saprophytic bacteria of water, soil, and sewage by the use of high temperatures, antiseptics, and other inhibitive influences to which the members of the colon-typhoid group are especially resistant, but the elimination of the always abundant B. coli cannot be so readily accomplished. The colon bacillus is in general more resistant than the typhoid bacillus and is far more richly endowed with the ability to initiate various reduction and fermentation processes.

The active motility of the typhoid bacillus as compared with the sluggishness of nearly all strains of colon bacilli is one of the few positive characteristics of diagnostic value. Several of the methods recommended for the isolation of the typhoid bacillus are based upon this quality. These methods have frequently given excellent results in the hands of the inventor, but have not always proved equally available in the hands of other experimenters. One of the most generally used in this country is the method of Hiss * (Fig. 73).

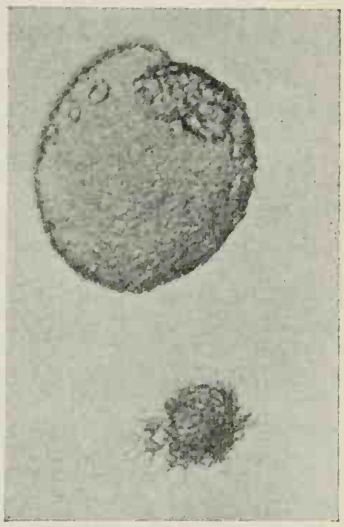


Fig. 73.—Deep typhoid and colon colonies in Hiss' medium, grown eighteen hours at 37°C. The typhoid colony is small, of loose texture, and has fringing threads. The colon colony is larger and without threads (Hiss).

Several varieties of colored media, some of which contain inhibitory agents, have won favor in recent years. The medium of Drigalski and Conradi † has been employed by many investigators. Various modifications of the original medium have been introduced. One formula successfully used by Harris is the following:

Dextrose-free broth	2000 c.c.
Nutrose	10 grams.
Agar	40 grams.

Boil, dissolve, neutralize to phenolphthalein, autoclave at 120° for five minutes. Clarify with whites of four eggs and filter. Then add: lactose, 30 grams; 1 per cent. litmus solution, 260 c.c.; crystal

* Hiss: Jour. Med. Res., 1902, 8, p. 148.

† Drigalski and Conradi: Ztschr. f. Hyg., 1902, 39, p. 283.

violet, 20 c.c. of 0.1 per cent. aqueous solution. The crystal violet exercises a marked restraining influence, most of the purely saprophytic bacteria never coming to development. In fourteen to twenty-four hours at 37° C. the colonies of B. coli appear red, opaque, and rather large, while the colonies of B. typhosus are relatively small and are transparent and blue. Not all of the translucent blue colonies are typhoid bacilli, however, and further tests are necessary to establish identification. Plates made with the Drigalski-Conradi medium have facilitated greatly the isolation of typhoid bacilli from excreta.

Endo * has prepared a fuchsin-lactose-agar decolorized by sodium sulfite which makes possible a somewhat similar differentiation between B. coli and B. typhosus, but which has not been very widely adopted.

Löffler † found that the addition of a dye known as malachite green to agar inhibited the development of B. coli, but permitted B. typhosus to form colonies. Different samples of malachite green vary considerably in their restraining power and must be tested separately. Some strains of B. typhosus appear to be affected by the malachite green as much as some strains of B. coli, but, as a rule, the selective action is pronounced.

Hoffman and Ficker,‡ basing their work on the observation of Roth that caffein checked completely the growth of B. coli in broth, but allowed B. typhosus to grow readily, have devised an enrichment method for the isolation of the typhoid bacillus. Nine hundred cubic centimeters of the suspected water are mixed with 80 c.c. of nutrose solution (containing 10 grams nutrose) and 20 c.c of freshly prepared caffein solution (containing 25 grams caffein). Ten cubic centimeters of a 0.1 per cent. crystal violet solution are added and the mixture incubated twelve to thirteen hours (no longer!!) at 37°. Not all observers have obtained equally favorable results with the caffein method, although by its aid Jaksch and Rau § isolated the typhoid bacillus from a suspected water.

* Endo: Centralbl. f. Bakt., 1904, 35, p. 109.

† Löffler: Deut. med. Wchnschr., 1906, 32, p. 289.

‡ Hoffman and Ficker: Hyg. Rundschau, 1904, 14, p. 1.

§ Jaksch and Rau: Centralbl. f. Bakt., 1904, 36, p. 584.

Klinger,* on comparing the four methods of isolation just described, obtained the largest number of positive results from typhoid stools by the malachite green method. Peabody and Pratt † report excellent results in isolating typhoid bacilli from feces by use of a malachite green broth. The proper dilution of malachite green and the proper reaction for the broth must be determined for each preparation of the dye. A full bibliography and useful critical review of various methods employed for isolating typhoid bacilli from stools has been given by Pratt.‡

Distribution of the Typhoid Bacillus in Nature.—The typhoid bacillus is by preference a parasite. Outside the human body it has been found only in those situations where it could be more or less directly traced to an origin in the discharges of a typhoid patient or convalescent. Many of the earlier reported findings of this organism in water and soil cannot now be given credence, owing to the inadequacy of the identification tests to which the cultures were subjected. Up to the present time relatively few well-authenticated instances have been recorded in which the typhoid bacillus has been found in water, soil, and similar situations. Laboratory experiments have shown that the typhoid bacillus can survive in sterile water in glass vessels for upward of three months, and for possibly two or three weeks in unsterilized ground or surface water. Other evidence indicates that the bacillus is able to travel in water a distance of at least 140 kms. (Gärtner §) and to retain its vitality in natural bodies of water for at least four or five days (Jordan, Russell, and Zeit ‖). It is possible that water may continue to be the vehicle of infection during a much longer period, but the available data point to a comparatively short duration of life of the specific germ in the water of flowing streams (Jordan, Russell, and Zeit). Under ordinary conditions no multiplication of the typhoid bacillus takes place in water, even when a considerable amount of organic matter is present, but, on the contrary, a steady decline in numbers goes on. The history of typhoid

* Klinger: Arb. a. d. kais. Gesund., 1906, 24, p. 35.

† Peabody and Pratt: Boston Med. and Surg. Jour., 1908, 158, p. 213.

‡ Pratt: Boston Med. and Surg. Jour., 1907, 156, pp. 744, 778, 813.

§ Gärtner: Klin. Jahrb., 1902, 9, p. 335.

‖ Jordan, Russell, and Zeit: Jour. Infect. Dis., 1904, 1, p. 641.

epidemics tends to show that sewage pollution is to be feared chiefly when the sewage is fresh, and that the danger of infection diminishes progressively with the lapse of time.

In soil and in the fecal matter of privy vaults the duration of life of the typhoid bacillus is much longer than in water. Levy and Kayser * found typhoid bacilli in soil that had been manured fourteen days previously with the five-months-old contents of a vault. The evidence that any genuine multiplication can take place in the soil is not convincing, but it has been proved that the bacillus may be carried by water-currents to a considerable distance from the point where it was first introduced. Infection of wells and small water-courses is thus brought about sometimes by the washing of bacilli out of soil in which they may have lain dormant for many months. The persistence of typhoid fever around certain habitations may be plausibly explained on the supposition of an extensive soil infection. There is no doubt that the practice of using human excrement for manuring vegetable gardens entails a danger no less real because often unrecognized.

The history of typhoid epidemics indicates that air-borne infection is, to say the least, exceedingly rare. Sewer air, so far as known, is never the vehicle by which the specific germ of typhoid fever is conveyed from one place to another.

Pathogenicity for the Lower Animals.—It has long been known that house pets and domestic animals do not become affected during epidemics of typhoid fever. Attempts to reproduce typical typhoid fever in the animals ordinarily used for laboratory experiments have not met with much success. The early experiments of feeding rabbits, guinea-pigs, and mice with typhoid cultures or infected food gave entirely negative results.

Later observers have obtained a more positive outcome. Remlinger,† for example, succeeded in producing a genuine infection by feeding vegetables smeared with typhoid bacilli to fasting rabbits and rats. But even in these experiments it must be admitted that there is no precise reproduction of the ordinary clinical picture of human typhoid fever. Grünbaum,‡ however, has reported

* Levy and Kayser: Centralbl. f. Bakt., 1903, 33, p. 489.

† Remlinger: Ann. de l'Inst. Past., 1897, 11, p. 829.

‡ Grünbaum: Brit. Med. Jour., 1904, 1, p. 817.

interesting results from feeding chimpanzees with typhoid cultures in milk and broth. On killing the animals twelve days after infection characteristic typhoid lesions were found in the ileum, and the typhoid bacillus was recovered from the spleen.

As regards the ordinary domestic animals, the available data point to a rapid destruction of the specific bacilli when they are introduced into the alimentary tract. It has been shown * that when the bacillus is fed to animals in considerable quantities it does not reappear in the feces; hence the fear that cattle drinking polluted water might become a means of spreading the disease through the multiplication of typhoid bacilli in their intestines, even though the animals themselves might not suffer from the disease, does not seem justified.

Intraperitoneal injection of typhoid bacilli has much the same effect upon animals as injection with colon bacilli (Pfeiffer and Kolle †). When introduced into the peritoneum in considerable quantity ($\frac{1}{50}$ to $\frac{1}{30}$ of a loop of a young, virulent agar culture), many strains of typhoid bacilli evince pathogenic properties. General symptoms of a non-specific character are set up and result fatally (six to eight hours) when a susceptible animal is inoculated with a considerable number of bacilli of sufficiently virulent strain. Although a genuine but slight multiplication of bacilli takes place in the peritoneum and attests the occurrence of a true infection, neither the symptoms nor lesions of this intraperitoneal typhoid bear any close resemblance to the typhoidal processes in man. The substance that is toxic for the organism is contained in the bodies of the bacilli, and is not a secretion product, as is shown by experiments with young sterilized cultures.

Pathogenicity for Man.—Typhoid fever (Eng., *enteric fever;* Ger., *Abdominaltyphus* or *Typhus;* Fr., *la fièvre typhoide*) is one of the most widespread and important of all bacterial diseases. In the United States in the census year, 1900, there were reported 35,379 deaths from this disease, and this number is probably considerably below the true figures. The number of deaths reported indicates that there were at least 350,000 cases of typhoid fever in a single year in a population of about 76,000,000, and that in the

* Stokes: Maryland Med. Jour., Nov., 1900.

† Pfeiffer and Kolle: Ztschr. f. Hyg., 1896, 21, p. 203.

course of a decade perhaps one person in every twenty or twenty-five contracts typhoid fever. These cases are caused by taking into the mouth germs discharged in human urine or feces, and the conditions that make this possible do not imply that a very advanced stage of civilization has been reached.

The physiologic accompaniments of typhoid fever are many and variable, and a diagnosis by clinical methods is often difficult, especially in the early stages of some cases. The common symptoms comprise frontal headache, want of appetite, nose-bleed, the development of rose spots on the abdomen, muscular weakness and diarrhea. There is, as a rule, a general step-like rise of temperature during the first week or ten days. On autopsy the intestinal walls are usually found extensively ulcerated, Peyer's patches and the solitary glands of the intestine being particularly involved and containing the specific bacillus. Perforation of the intestinal wall as a consequence of ulceration is a serious and not infrequent occurrence. The spleen is enlarged and congested, and usually contains large numbers of typhoid bacilli.

In addition to the more or less constant symptom-complex, recognized as the definite disease of typhoid fever, there are certain other pathologic conditions of the human body with which the typhoid bacillus stands in causal relation. Inflammation of the urinary bladder (cystitis) sometimes occurs as the result of infection of the urine. The gall-bladder also is very commonly affected and severe inflammations of this organ are sometimes noted.

Suppurative and inflammatory processes (metastases) may be kindled by the typhoid bacillus in many parts of the body. The osseous system seems especially open to attack, and affections of the periosteum, the bone-marrow and the joints have been traced to infection with B. typhosus. Osteomyelitis may develop as long as six or seven years after recovery from typhoid fever has taken place. Particular interest attaches to these cases, since they show that the typhoid bacillus can remain for years in contact with the human tissues and presumably be exposed to the action of the protective substances in the blood without losing its virulence.

Other parts and organs of the body are more rarely invaded by the typhoid bacillus, but under certain conditions almost any organ may be attacked. The presence of the bacillus has been

reported in a brain abscess.* The cerebral and meningeal symptoms occurring in many cases of typhoid fever are directly connected with the localization of the typhoid bacilli in the meninges, and the bacilli have been obtained in the fluid drawn by lumbar puncture.†

Secondary or mixed infections, especially with the pyogenic cocci and the pneumococcus, are not at all uncommon, and sometimes cause serious complications. Mixed infections with the tubercle bacillus, the diphtheria bacillus, and B. anthracis (Karlinski‡) have been known to occur.

The intestine has long been considered as the main if not the sole portal of entry of the typhoid bacillus, but other possibilities have been suggested by recent investigation. The actual evidence in favor of invasion of the body through the tonsils and gastric mucosa is considered by some investigators to be quite as strong as the evidence for intestinal penetration. In any case there is no doubt that typhoid fever is a general and not a localized infection.

Distribution of Bacilli within the Body of the Patient.— In correspondence with the frequency of intestinal symptoms and lesions typhoid bacilli might be expected to be commonly present in the feces and intestinal contents of typhoid patients. Great difficulty, however, is often experienced in isolating them from feces, owing partly, no doubt, to their association with a multitude of colon bacilli and related organisms. Many special methods, some of which have been already described, have been advocated for facilitating isolation. The largest number of positive findings are reported as made between the seventh and twenty-first days of the disease, so that in the majority of cases a positive result is not obtained until such a period that the nature of the malady is evident on clinical grounds. Part of the difficulty in isolation is due to the real scarcity of typhoid bacilli in feces. The fact that typhoid bacilli usually occur in small numbers in the stools of typhoid patients and are not infrequently altogether absent has led some recent investigators to believe that the bacilli do not multiply in the intestinal contents except under unusual conditions. It is believed

* McClintock: Amer. Jour. Med. Sci., 1902, 123, p. 595.

† Cole: Johns Hopkins Hosp. Rep., 1904, 12, p. 379.

‡ Karlinski: Berl. klin. Wchnschr., 1888, 25, p. 866.

also that the typhoid bacilli in the intestine come chiefly from the bile.*

In the urine typhoid bacilli are found in about 25 per cent. of all cases, sometimes in conjunction with the colon bacilli, but often in pure culture. They may occur in enormous numbers; in some cases observers have found from 100,000,000 to 500,000,000 in a cubic centimeter of urine. Cystitis is occasionally produced as a result of urine infection, but is not a necessary sequel. The urine may remain infectious far into convalescence unless some method of sterilization of the bladder be resorted to. The administration of urotropin by mouth has proved most suitable for this purpose, and good results have been obtained by washing out the bladder with a solution of mercuric chlorid (Richardson †). Typhoid bacilli sometimes persist in the urine for weeks and months after recovery (seven years, Young ‡). The danger of dissemination of typhoid fever by means of the infected urine of convalescents is especially great, and appropriate methods for the treatment of the urine as well as the feces of typhoid patients should be uniformly employed in all cases.

The bile becomes frequently infected during an attack of typhoid fever, as shown by post-mortem examinations. In experiments upon rabbits Blachstein § found living typhoid bacilli in the gall-bladder, in one case as long as one hundred and twenty-eight days after intravenous injection and after the other organs had become entirely free. If an inflammatory process is set up in the gall-bladder or duct, typhoid bacilli may continue to be discharged into the intestine with the bile for practically indefinite periods.‖ The epidemiologic significance of persistent bile infection has only recently come to light. The so-called chronic bacillus-carriers are, in many cases at least, persons with typhoid bacilli in their gall-bladders. In the German campaign against typhoid fever in the Rhine provinces, it has been observed that a large proportion of all

* For a review of this subject with full bibliography see an article by Pratt, Peabody, and Long, Jour. Amer. Med. Assoc., 1907, 49, p. 846.

† Richardson: Jour. Exp. Med., 1898, 3, p. 349.

‡ Young: Johns Hopkins Hosp. Rep., 1900, 8, p. 401.

§ Blachstein: Johns Hopkins Hosp. Bull., 1891, 2, p. 96.

‖ Seven years, Miller: Johns Hopkins Hosp. Bull., 1898, 9, p. 95.

persons who suffer from gall-stones are discharging typhoid bacilli in their feces.

Typhoid bacilli have been found occasionally in the *sputum*, although the majority of cases of pneumonia that occur during the course of typhoid fever are apparently caused by the pneumococcus. There is hence a possibility that typhoid fever may be spread by sputum infection, but it seems rather remote.

The *rose spots* that appear on the abdomen in about 80 per cent. of cases of typhoid fever are to be considered as a specific eruption due to the presence of typhoid bacilli. The earlier attempts to isolate the bacilli from the rose spots failed usually because a large amount of blood was drawn and insufficiently diluted with broth, thus allowing opportunity for the action of the germicidal substances in the blood. By proper methods the bacilli can be isolated from the rose spots at an earlier period in the disease than from the feces, and, indeed, earlier than the agglutination reaction makes its appearance.*

The examination by suitable methods † of the blood of typhoid patients during life has shown that in the great majority of cases bacilli are present in the blood-stream very early in the course of the disease. Diagnosis is often possible by blood examination earlier than by other methods. After death the bacteria are found in practically all the important organs and tissues.

The general distribution of the typhoid organism throughout the body has caused some modification in our conception of the pathology of typhoid fever. In the light of all the facts cited this disease must now be looked upon as a general invasion of the body, particularly of the lymphatic system, rather than as a purely localized infection with its seat in the wall of the alimentary tract.‡ Coleman and Buxton§ have advanced the view that the lymphatic

* Neufeld: Ztschr. f. Hyg., 1899, 30, p. 498.

† A considerable quantity of blood must be mixed with a much larger quantity of broth or fluid agar immediately after it is drawn, to prevent the action of the germicidal substances in the blood.

‡ The finding of the bacillus in the blood has led some writers to speak of typhoid fever as a "modified septicemia." There is no good evidence, however, that the bacilli are multiplying in the blood, which is strongly bactericidal.

§ Coleman and Buxton: Jour. Med. Res., 1909, 21, p. 83.

tissues in the intestinal wall are first invaded, and that thence the bacilli spread to the general lymphatic system and the spleen. After considerable multiplication has occurred (incubation period), the bacilli overflow into the blood and bacteriolysis takes place; the endotoxins which are liberated as the result of the destruction of the bacilli produce the symptoms of typhoid fever.

Epidemiology.—The predilection shown by typhoid fever for certain localities and for certain seasons have given rise to many speculations concerning the influence of atmospheric and telluric conditions, and at one time led to the promulgation by Pettenkofer of a theory of the "ripening" of typhoid germs in the soil. The influence of locality in itself, apart from its possible influence upon the character of the water-supply, does not now seem to be important, although a city with a badly infected water-supply, as for many years Pittsburg, Penna., may become the center of a typhoid ravaged district. This is not because of any peculiarity of soil or climate, but because new foci of infection are continually being kindled and the disease is kept alive by the great abundance of infectious material. Sedgwick has proposed the apt term *prosodemic* to designate the general diffusion of a disease among the people of a community. The seasonal incidence of the disease,* in early autumn, has not been fully explained.

In recent years many of the most obscure and perplexing facts in the distribution of typhoid fever have had light thrown on them by the discovery of the intimate relation borne by typhoid patients and convalescents to the further spread of the infection. In all the epidemiology of this disease the human being that carries the bacillus is the central figure. Typhoid bacilli leave the body, as a rule, in either the feces or the urine, pass into the external world, and find their way more or less circuitously to the alimentary tract of another individual. There proliferation may again begin, and a new focus of infection comes into existence. Outside of the human body, multiplication, if it occurs at all, is insignificant, and for practical purposes may be neglected as a factor in the dissemination of the disease. So far from multiplying freely, typhoid bacilli, when discharged from the body, undergo progressive diminution in numbers, and it is probable that the majority perish under ordinary

* In Europe and North America

conditions within a few days, although in masses of fecal material some bacilli may remain alive for relatively long periods. The principal channels by which the typhoid bacillus makes its way to fresh victims will be briefly considered.

(*a*) *Water.*—There is unfortunately too intimate a connection between sewage-disposal systems and water-supplies. The remarkably rich epidemiologic literature of typhoid fever shows a great preponderance of large epidemics of water-borne infection. Schuder,* in a compilation of 638 epidemics of typhoid, found that 71 per cent. were attributed to infected drinking-water. Manifold instances have been reported where typhoid fever has been definitely traced to the use of water from a polluted well or spring, only those individuals being affected who used the water from the contaminated source. Weichselbaum †* records the curious case of a certain house in Stuttgart which was invaded by typhoid fever during an epidemic caused by an infected town water-supply. Only those persons living on the second and fourth floors of this house were affected; the dwellers on the first and third floors were exempt and were found to use well-water.

A typical outbreak of typhoid fever, traced to a specific pollution of the water-supply, is reported by Thresh.‡ A number of typhoid cases occurred in the small town of Halsted in the northwestern part of the county of Essex, England. Investigation showed that at the time of the outbreak there was on the outskirts of the town a public drinking-fountain, which was fed by subsoil water, the surplus water from this fountain being piped to the cottage of a workman in the town. Above the source of the spring supplying the fountain, and near the top of a hill, an isolation hospital had been recently erected. A short time after the first patient ill with

* Schuder : Ztschr. f. Hyg., 1901, 38, p. 343. Schuder's statistics on their face convey a somewhat exaggerated idea of the frequency of water infection, since the larger and more explosive outbreaks are mainly due to water and are the ones ordinarily placed on record, while small epidemics and isolated cases are less likely to be deemed worthy of report. Although the water epidemics are most conspicuous, it is noteworthy that the mortality from typhoid fever in the United States at the present time is greater in rural communities than in cities. (Fulton: Jour. Amer. Med. Assoc., 1904, 42, p. 73.)

† Weichselbaum: Weyl's Handbuch d. Hyg., 1900, 9, p. 436.

‡ Thresh: Lancet, 1897, 1, p. 687.

typhoid fever had been placed in the isolation hospital the man residing at the cottage supplied with water from the fountain was attacked by typhoid fever. The only likely source of the disease was the drinking-water, since this man had not been in communication with the family in which typhoid fever had developed, and had not been away from the town for over two months. A little later four children developed typhoid fever, and all of these acknowledged that they had drunk more or less frequently at the fountain in passing. About two weeks later another child was attacked with typhoid fever, and although four other children in the house in which this child lived attended the same school, only the one affected had drunk the fountain water. On further inquiry the pipes conveying the water to the fountain were found to cross the roadway and pass underneath the sewer leading from the isolation hospital; in fact, they were almost in contact with the sewer-pipe. The water-pipes were ordinary agricultural drain-pipes, while the sewer-pipes were earthernware with plugged joints, and the latter were so damaged that during heavy rains any leakage from the sewer could enter directly into the water-pipes. Bacterial examination of the water showed not only the presence of B. coli, but also of an organism which, by all the tests then applied, resembled very closely the typical typhoid bacillus. There were no other likely sources of infection in this neighborhood.

Besides such specific cases it has also happened repeatedly that a city on changing from a polluted to a pure water-supply has experienced an immediate reduction in the prevalence of typhoid fever. The city of Albany, New York, has had its typhoid death-rate diminished to about one-third as a result of the introduction of a system of sand filtration. In Vienna the abandonment of the polluted Danube River water was followed by a decline in the annual typhoid death-rate from 100-340 to 6-8. In the city of Paris, which at times has been obliged to eke out its insufficient supply of spring-water with the highly polluted water of the River Seine, it has been observed that a miniature epidemic of typhoid springs up in that district of the city temporarily supplied with the Seine water and follows from one part of the city to another the course of the impure water as it is turned now into the pipes of one section, now into those of another.

The largest explosive outbreaks of typhoid fever in the United

States due to water infection have been those at Plymouth, Penna.* (1885, 1104 cases, 114 deaths), Ithaca, N. Y.† (1903, 1350 cases, 82 deaths), and Butler, Penna.‡ (1903, 1346 cases, 111 deaths).

Experiments have shown that when water freezes the great majority of typhoid bacteria that it contains are immediately destroyed. Those that survive die off progressively. According to Park, not one in a thousand lives in ice longer than one month, and at the end of six months all are dead. The use of ice is therefore not so dangerous as the use of the water from which it is formed. Relatively few epidemics of typhoid fever have been proved to be due to the use of ice. Convincing evidence, however, that ice infection does sometimes occur is given in a report of Hutchings and Wheeler,§ who showed that the use of ice in the St. Lawrence State Hospital near Ogdensburg, N. Y., was followed by an epidemic of thirty-nine cases. The ice was cut seven months before its use, from the St. Lawrence River about three miles below the point where the Ogdensburg sewage entered the river. Living typhoid bacilli were isolated from samples of the melted ice examined after the breaking out of the epidemic.‖

(*b*) *Milk.*—Some and perhaps the majority of outbreaks of typhoid fever due to infected milk owe their origin to the use of polluted water for rinsing cans, bottles, and other utensils employed in the collection and transportation of the milk, a few drops of water being inadvertently left in the vessel in which the milk is placed. Other outbreaks are caused by direct infection of the milk through the agency of persons suffering from mild or ambulant cases, or of chronic germ-carriers engaged in processes that entail possible contact. The clue to the origin of milk epidemics is usually afforded by the development of cases of the disease along the route

* First Ann. Rep. State Bd. of Health and Vital Statistics of Pennsylvania, 1886; see also Sedgwick: "Principles of Sanitary Science and Public Health," pp. 200–206.

† Jour. Amer. Med. Assoc., 1903, 40, pp. 781, 913; Jour. New Eng. Water-Works Assoc., 1904, 18, p. 431.

‡ Jour. Amer. Med. Assoc., 1903, 41, p. 1476; Eng. News, Dec. 21, 1903, Twentieth Ann. Rep. of Penna. State Bd. of Health, 1904.

§ Hutchings and Wheeler: Amer. Jour. Med. Sci., 1903, 126, p. 680.

‖ See also W. H. Park: "The Importance of Ice in the Production of Typhoid Fever," Jour. Amer. Med. Assoc., 1907, 49, p. 731.

of a particular milkman, while at the same time neighboring families served with milk from other sources remain free from infection. Since typhoid bacilli, in contrast to their behavior in water, are able to multiply in milk, the establishment of creameries in which the custom prevails of mingling milks from many different farms increases the peril of diffusion, since milk from a single source may infect the entire output of a creamery. Milk epidemics are often mild in type and affect a proportionally large number of women and children. Butter made from infected cream is a possible vehicle for typhoid infection; experiments in fact have shown that typhoid bacilli introduced into butter in large numbers can survive for as long as twenty-seven days. Epidemiologic evidence of infection from eating butter is lacking.

(*c*) *Other Food Substances.*—Besides dairy products, other foods that are usually consumed in a raw state may be the means of conveying the disease. Oysters and other shellfish have come into particularly bad repute in this respect within recent years, for the reason that a number of typhoid epidemics in Great Britain and the United States have been found to be due to the eating of oysters grown near sewer outfalls or placed to "fatten" in the polluted waters of estuaries or creeks.* Water-cress, lettuce, radishes, or any vegetables or fruits which are liable to come in contact with contaminated water or are sprayed with excrementitious matter are also capable of conveying infection.

(*d*) *Flies.*—Contamination of various articles of food by the wandering house-fly has long been a recognized possibility, but its importance and relative frequency have only recently become known. The severe visitation of typhoid fever in the camps of American soldiers during the Spanish-American War is in large part plausibly attributed to infection of this character.† Lime was used for disinfecting the latrines in these camps, and flies with whitened feet were subsequently seen walking over the food. Not only may bacilli stick to the legs and wings of these insects,

* For a concise summary of the data upon oyster infection, with full bibliography, see an article by G. W. Fuller, Journal of Franklin Institute, Aug., 1905, p. 81.

† Abstract of Report on Origin and Spread of Typhoid Fever in U. S. Military Camps during the Spanish War of 1898. Reed, Vaughan, and Shakespeare, Washington, D. C., 1900. See also Report upon Typhoid Fever in Winnipeg, E. O. Jordan, 1905.

but if swallowed they may survive the passage of the alimentary tract. Typhoid bacilli have been isolated from house-flies captured in houses in Chicago in the neighborhood of badly kept privy vaults used by typhoid patients, and it has been shown experimentally that living bacilli may remain in or upon the body of flies for as long as twenty-three days after infection.* It is possible that other insects, such as cockroaches, may in a similar way act as mechanical carriers of typhoid bacilli to food-substances.

(*e*) *Dust.*—Typhoid bacilli may conceivably sometimes be inhaled in infected dust, but according to our present knowledge such mode of infection must be extremely rare. Cases formerly attributed to air-carriage may perhaps be more reasonably ascribed to the agency of flies. Food, however, may be contaminated by means of sand or dust storms in infected localities. This seems to have been an important factor in the causation of typhoid fever among the British troops in the South African War.

(*f*) *Contact.*—Under the head of contact may be included those cases of infection due to particularly direct and immediate transfer from the infected to the healthy. The liability of those who nurse typhoid fever patients to contract the disease is well known. Since a drop of urine or a small particle of fecal matter may contain many thousands of typhoid bacilli, it is safest to regard the immediate surroundings of all typhoid patients as infected, and to institute appropriate precautions. In almost countless ways typhoid bacilli may find access to the alimentary tract of attendants or associates. Cases of direct infection are unquestionably more common than is generally recognized. Many cases due to secondary or contact infection follow in the wake of every epidemic of water-borne origin. The existence of "germ-carriers" accentuates the danger of contact infection.

The term "chronic germ-carrier" has been applied by German writers to those persons in whose bowel or bladder discharges typhoid bacilli can be detected at least ten weeks after convalescence. In Lentz's experience, about 4 per cent. of all cases of typhoid patients that are submitted to bacteriologic examination fall in this category.†

Bacilli are sometimes discharged, as shown by exact bacteriologic control, for at least two years, and probably in some cases

* Alice Hamilton: Jour. Amer. Med. Assoc., 1903, 40, p. 576.

† Klin. Jahrb., 1905, 14, p. 475.

for a much longer period. Typhoid germ-carriers are unquestionably responsible not only for occasional infection of water and milk, but for direct contact infection of the immediate associates and comrades. Soper* has brought to light a remarkable instance of a New York cook who was the innocent cause of some twenty-six cases of typhoid fever in seven different families. In the majority of these cases, as already pointed out, the bacilli seem to have established themselves in the gall-bladder. Attempts to secure an internal disinfection and prevent the continued elimination of bacilli have so far been unsuccessful.†

Immunity.—An unmistakable attack of typhoid fever confers a certain degree of immunity, although instances of two or even more attacks in the same individual are not unknown. It seems likely also that certain mild forms of intestinal disturbance, which are in reality light but unrecognized cases of typhoid fever, afford a certain protection against the severer forms of the disease. The relative freedom from typhoid shown by the permanent residents of a city having an impure water-supply, as compared with the susceptibility of the stranger within the gates, may perhaps be explained in this way.

Experiments with animals have shown that it is possible to obtain a high degree of immunity in rabbits and guinea-pigs against intraperitoneal inoculation. This can be brought about by gradually increasing the amount of intraperitoneal bacterial injection, the animals after appropriate treatment being able to withstand many times the original fatal dose. The immunity is associated with the acquisition by the body-fluids of a specific germicidal power. When typhoid bacilli are introduced into the peritoneum of an immunized animal, they are speedily dissolved and disintegrated by the peritoneal fluid in a manner not observed in a normal animal (Pfeiffer's phenomenon). Pfeiffer and Kolle‡ also showed that the simultaneous injection of immune serum and typhoid bacilli into a normal animal led to a similar destruction of the bacilli, while control animals that were inoculated with bacilli alone died. The development of this germicidal property in the body-fluids is due to substances

* Soper: Jour. Amer. Med. Assoc., 1907, 48, p. 2019.

† See, however, a report on the effect upon the bile of administering urotropin. Crowe: Johns Hopkins Hosp. Bull., 1908, 19, p. 93.

‡ Pfeiffer and Kolle: Ztschr. f. Hyg., 1896, 21, p. 203.

contained in the bacterial cells. The injection of filtered broth cultures does not impart any bacteriolytic power to the serum.

The nature of the germicidal action and the mechanism concerned in it are described elsewhere. The bactericidal power of immune serum may be observed in test-tube experiments as well as in animal inoculation. To a mixture of normal serum and typhoid bacilli graduated quantities of the serum of an immunized animal or typhoid convalescent are added and allowed to stand for a definite period. Plates are then made and the dilution noted at which bactericidal action is manifest. There is no constant relation between the bactericidal power of a serum in a test-tube and that of the same serum in the animal body. At the height of the disease when the serum shows its highest potency in the test-tube

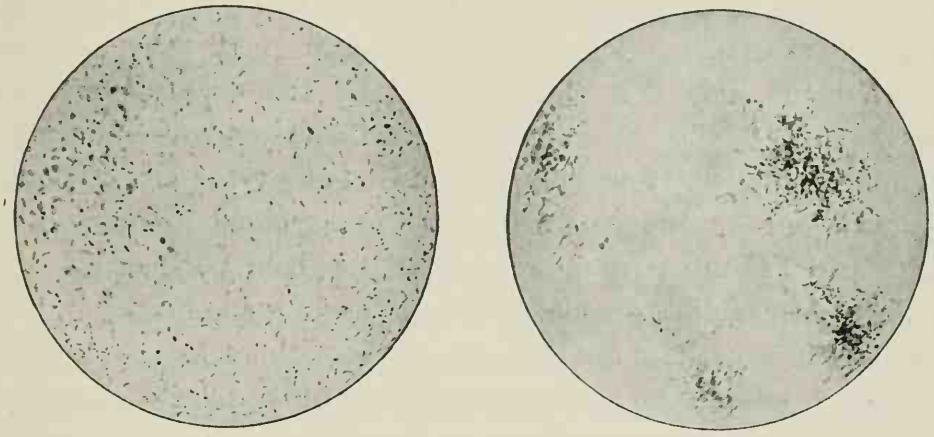


Fig. 74.—Application of the serum-reaction to typhoid bacilli. A shows the distribution of the bacilli before the reaction. B shows clumping of the motionless bacilli after mixture with the serum of a case of typhoid fever.

experiment, the same serum mixed with bacilli and introduced into the animal body often exerts little or no germicidal effect.

Agglutination.—Not only a germicidal substance, but also, as is well known, an agglutinating substance, makes its appearance within the body of inoculated animals. In other words, the blood-serum of animals which have been injected with typhoid bacilli possesses the property of clumping or agglutinating suspensions of typhoid bacilli (Fig. 74). This reaction may be observed either with the microscope or, under suitable conditions, in a small test-tube with the naked eye, since the clumps of agglutinated bacteria form visible flocculent particles which eventually settle to the bottom of the tube as a fine sediment.

The agglutination phenomenon (Gruber-Widal reaction) has been utilized extensively for the purpose of diagnosing typhoid fever in man. The fact that the serum of typhoid patients in rather high dilutions causes agglutination in the vast majority of instances (over 90 per cent. in the fourth week of the disease), while the serum from normal individuals and from those suffering from other diseases than typhoid fever does not possess the same power, has been taken advantage of to facilitate the recognition of clinically obscure cases of the disease. In making the test the serum should be mixed with an authentic culture of typhoid bacilli in a dilution of not less than 1:50, since serum from normal individuals may produce agglutination in lower dilutions. Although the microscopic reaction is more delicate, that is to say it can be observed in lower dilutions, the macroscopic test is less open to error even for experienced observers. Beginning agglutination may often be seen in two hours, and may be confirmed by the twenty-four hour appearance. As has been already pointed out, some cases clinically resembling typhoid fever may be caused not by the true typhoid organism, but by some member of the paratyphoid group, and in such cases agglutinative power for the typhoid bacillus may be lacking. The ability to agglutinate is usually manifested by the blood-serum as early as the fifth day, but sometimes does not appear until much later. The agglutinative power of the blood-serum does not vanish soon after the blood is drawn, as does the germicidal property, but may persist with slightly diminished intensity for many months. Dried blood and blood-serum retain the capacity for agglutination, and the use of dried blood-serum in municipal laboratory work is very general (Wyatt Johnston). Many difficulties and sources of error beset the application of the agglutination test in practice. Some strains of typhoid bacilli are inagglutinable, and, in general, freshly isolated cultures are less sensitive than those that have been under cultivation for some time. If broth cultures are used, an inexperienced observer might be deceived by the spontaneous clumping that sometimes occurs in this medium; a suspension in physiologic salt solution of bacilli from an eighteen-hour-old agar culture is preferable. A series of mistaken conclusions is made possible by the occurrence of group-agglutinins (p. 161). Especially the serum of persons infected with B. paratyphosus **B**

may agglutinate the typhoid bacillus, and the same is true of infections with B. proteus (p. 382). For an absolutely sure diagnosis, it is desirable to make parallel tests with the typhoid bacillus and B. paratyphosus **B,** although at present the treatment of a case could hardly be affected by the outcome. The instances in which the serum of an undoubted typhoid patient agglutinates the paratyphoid bacillus more strongly than the typhoid bacillus itself are so rare as to have no practical significance.

The agglutination test is utilized not only for the purpose of distinguishing typhoid fever from other diseases, but also for differentiating the true typhoid bacillus from closely related organisms of the same group. The blood-serum from a typhoid patient may be used for this test, and serum may also be used from an animal (rabbit, goat) which has been inoculated with a typhoid culture of undoubted genuineness. To avoid sources of error due to the generation of a certain degree of agglutinative power for other organisms of the group, dilutions as high as 1:1000 must be used. The use of the agglutination test for identification is open to the practical limitation that the test may exclude organisms of great biologic similarity to the typhoid bacillus and possibly of similar pathogenic, if not agglutin-producing power. Inagglutinable strains of genuine typhoid bacilli are met with occasionally.

Serum-therapy and Protective Inoculation. — Although Chantemesse,* of Paris, and some others have reported favorable results from treating typhoid patients with a specific serum, the majority of observers have found that the use of serum from animals inoculated with typhoid bacilli or their products has little or no effect upon the course of the disease. On the other hand, protective vaccination against typhoid fever has been, on the whole, successful. The vaccines prepared by different experimenters are not precisely alike, but all contain bacterial cells or substances derived from them. Agar or broth cultures killed by heat have been used most extensively. In India, Egypt and South Africa many thousands of British soldiers and others have been vaccinated by Wright or under his direction.† The results reported show that about one-half as many cases occur among the vaccinated as among the non-vac-

* Chantemesse: Gaz. des Hôpitaux, 1898, 71, p. 397.

† Wright: Phila. Med. Jour., 1900, 6, p. 688; Lancet, 1902, 2, p. 651.

cinated and that the case-mortality is likewise lessened. A second injection increases the degree of protection. Wright's statistics have been subjected to severe criticism, but after making all allowances, there can be no doubt that the inoculations confer some measure of protection. Among the German troops in South Africa favorable results from inoculation with killed agar cultures have also been noticed. In four hundred and twenty-four cases of typhoid fever, three hundred and twenty-four not inoculated, and one hundred inoculated, there was a mortality of 11.9 per cent. in the non-inoculated group, 7 per cent. in the inoculated.

The use of a protective inoculation would seem to be desirable where special danger of typhoid infection exists, as among hospital nurses and attendants, and especially among soldiers living under the unhygienic conditions of war-time.

THE DYSENTERY BACILLUS (BACILLUS DYSENTERIAE)

The name dysentery is primarily a clinical term, and is applied to several diseases or pathologic conditions of the alimentary tract that exhibit similar symptoms, such as intestinal pain and blood in the stools; as a matter of fact, different kinds of dysentery exist, due to different causes. One variety of dysentery, the so-called amebic dysentery, is caused by a protozoon, and is considered elsewhere in this book (p. 438). A bacterial form of dysentery is also known, caused by bacilli of the colon-typhoid group.

In 1898 the Japanese bacteriologist Shiga,* while studying a severe epidemic of dysentery in Japan, could find no amebæ in the stools. He did, however, succeed in isolating a bacterium much like the typhoid bacillus. This micro-organism possessed certain definite characters, was found in the stools in all cases of epidemic dysentery, and was agglutinated by the serum of dysenteric patients in high dilutions. *Shiga's bacillus* is today generally regarded as the specific microbe of the acute epidemic form of dysentery most common in temperate climates.

Characteristics of the Dysentery Bacillus.—Microscopically and in its staining reactions B. dysenteriæ is very much like B. typhosus (Fig. 76). Motility has been rarely observed, and most

* Shiga: Centralbl. f. Bakt., 1898, 23, p. 599.

observers have failed to find flagella.* The growth on gelatin and agar and on potato resembles that of B. typhosus (Fig. 75). An alkaline reaction, however, is produced in milk. Neutral red agar is not decolorized. Acid is produced in glucose broth. Indol is not formed.

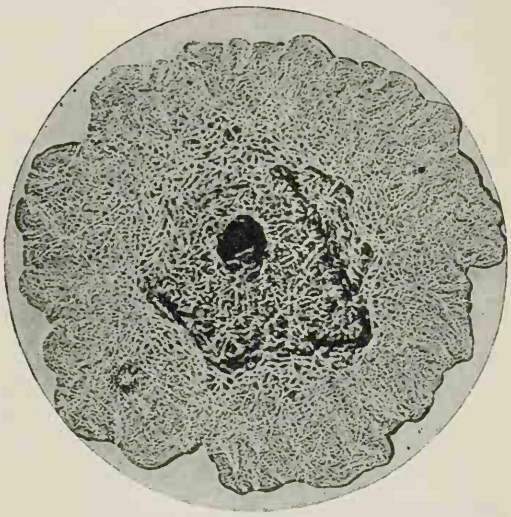


Fig. 75.—Bacillus dysenteriæ. Colony on gelatin, four days; × 20 (Doerr).

Varieties.—Bacilli identical with Shiga's bacillus in their morphologic, cultural, and agglutinative characters have been isolated in epidemics of dysentery in parts of Asia, Europe and North America. In some cases, however, different although closely related bacteria have been found. Flexner† when in Manila isolated from dysenteric stools an organism at first supposed to be of the Shiga type, but later discovered to differ in agglutinative and other characteristics. Martini and Lentz,‡ as the result of an extensive comparative study of bacilli isolated in epidemics of dysentery in different parts of the world, concluded that two types could be distinguished—one, the true Shiga bacillus, another of which the Flexner-Strong cultures from Manila were an example. Many cultures that had been obtained

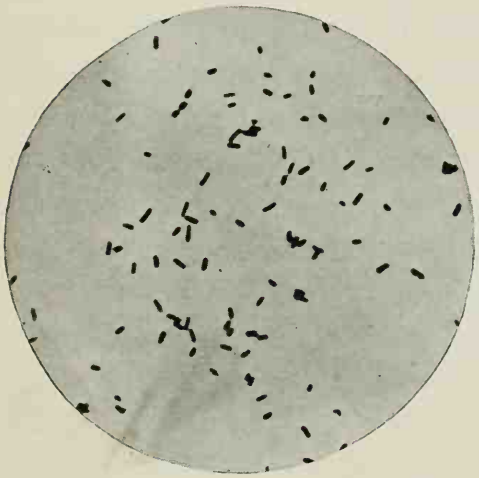


Fig. 76.—Bacillus dysenteriæ from agar culture. Fuchsin stain. Zettnow prep. (Kolle and Wassermann).

* See, however, Goodwin: Park, "Pathogenic Bacteria and Protozoa," N. Y., 1905, p. 254.

† Flexner: Centralbl. f. Bakt., 1900, 28, p. 625.

‡ Martini and Lentz: Ztschr. f. Hyg., 1902, 41, pp. 540, 559.

from dysenteric stools were found to belong to the latter type. The two varieties differ not only in agglutinating reactions, but also in fermentive power: the Manila type breaks down mannite, with acid production, while Shiga's bacillus is unable to attack this substance. Later a third type was isolated by Park* in an epidemic at Mt. Desert. Hiss† succeeded in differentiating the dysentery bacilli by means of their fermentive reactions and established four groups on this basis.

B. dysenteriæ.	Acid Production From:				Indol Production.
	Mannite.	Maltose.	Saccharose.	Dextrose.	
Type I (Shiga)	—	—	—	+	—
Type II (Park, Hiss)	+	—	—	+	+
Type III (Flexner-Strong, Manila)	+	—	+	+	+
Type IV (Harris-Wollstein)	+	+	+	+	+

The distribution, frequency of occurrence, and characteristics of these types have been largely studied by American investigators.‡ Shiga § has adopted the classification of Hiss as tabulated above and has added a fifth group, which differs from Type IV, in that it gives at first an acid reaction in mannite media, but later produces a permanent alkalinity. Otho‖ has even separated dysentery bacilli into fifteen groups, which have fermentation characters distinguishing them from one another. He considers that the mannite-fermenting type, as a rule, gives rise to severer forms of disease than the non-fermenting ones. American investigators are agreed that infections with Types II, III, and IV are, on the whole, less severe than those with Shiga's bacillus. Bacilli of Types III and IV are found more frequently than the Shiga bacillus in the dysentery or summer diarrhea of young children.

Pathogenesis.—As already stated, the serum of patients

* Park: N. Y. Univ. Bull., 1902, p. 187.

† Hiss: Jour. Med. Res., 1904, 13, p. 12.

‡ See, for example, Park, Collins, and Goodwin, Jour. Med. Res , 1904, 11, p. 553.

§ Shiga: Philippine Jour. of Sci., 1906, 1, p. 485.

‖ Otho: Philippine Jour. of Sci., 1906, 1, p. 951.

suffering from acute dysentery agglutinates Shiga's bacillus in high dilutions. This fact and the constant occurrence of the bacillus in the stools afford powerful arguments for a causal connection. Apart from the inflammatory, sometimes ulcerative or diphtheritic lesions in the intestine (ulcerative colitis), the anatomic picture of dysentery presents little that is characteristic. The liver abscesses that are found, as a rule, in amebic dysentery are absent in the bacterial disease, one series having been reported of 1130 cases of bacillary dysentery without a single abscess. B. dysenteriæ is sometimes found in immense numbers in the dejecta, often in almost pure culture. It is found at autopsy in the mesenteric glands, but, as a rule, not in the spleen or other internal organs, nor does it occur in the blood or urine. Bacterial dysentery is therefore an infection localized in the alimentary tract, in this respect resembling Asiatic cholera rather than typhoid fever. The spread of the disease is probably due to the more or less direct transfer of the specific bacillus from infected intestinal discharges to the alimentary tract of a fresh individual. Polluted water has been shown to be responsible for many epidemics. Dysentery, like typhoid fever, is a terrible scourge of armies. In general, the modes of dissemination in this disease must be similar to those in typhoid fever, flies and contact infection doubtless playing a large part. The danger from mild and unrecognized cases, and perhaps also from convalescent germ-carriers, seems especially worthy of consideration.

Duval and Bassett * isolated B. dysenteriæ from the feces of forty-two out of fifty-three cases of summer diarrhea in infants. Subsequent investigators also found the dysentery bacillus in certain cases of infantile intestinal disturbances, especially those in which there is mucus in the stools. Those cases with which B. dysenteriæ is associated do not appear to differ clinically from those in which it is not found. It is uncertain just what proportion of cases of infantile diarrhea are caused by the dysentery bacillus.†

Feeding animals with B. dysenteriæ is not generally successful in reproducing the symptoms or lesions of human dysentery, although rabbits and guinea-pigs are highly sensitive to intravenous and intraperitoneal inoculation with living or dead bacilli, and die with

* Duval and Bassett: Amer. Med., 1902, 4, p. 417.

† See Studies from the Rockefeller Institute for Medical Research, 1904, 2.

symptoms of acute poisoning. Shiga has observed intestinal lesions in experiment animals similar to those of human dysentery.

Toxins, Serum-therapy, etc.—According to various investigators, both extracellular and intracellular poisons are obtainable from cultures of B. dysenteriæ. The death of a rabbit has been produced in twenty-four hours by intravenous injection of 0.02 c.c. of the filtrate of a seven-day broth culture, and extracts of agar cultures also possess toxic qualities. Klein * maintains that there is only one poisonous substance, an endotoxin, which occupies an intermediate position between the well-known endotoxins (typhoid bacillus, cholera spirillum) and the toxins of diphtheria and tetanus. Like the latter substances, the toxin of dysentery is able to give rise to an antitoxin. Flexner,† upon injecting rabbits intravenously with the products of autolytic digestion of dysentery bacilli, observed the production of intestinal lesions analogous to those of human dysentery. In such a case the lesions would seem to be due to the elimination of the poison from the blood into the intestine and to the consequent contact of the poison with the intestinal tissues. Dopter‡ has shown that the products of the Shiga bacillus may cause paralysis in rabbits, the paralysis being referable to acute lesions in the ponto-bulbar region or gray substance of the spinal cord, and Herter § has suggested that some cases of infantile spinal paralysis may be due to dysenteric infection.

Shiga and some other investigators have treated dysentery patients with the serum of horses injected with dysentery bacilli and their products, and have obtained favorable results, the mortality being reduced about one-half in the cases reported. A polyvalent serum, that is, one prepared by the use of several types of dysentery bacilli, is recommended by Shiga. The anti-dysenteric serum is said to be both bactericidal and antitoxic. Theoretically and in its practical application serum-therapy in dysentery needs further study before it is likely to come into general use.

B. fecalis alkaligenes ‖ closely resembles the typhoid bacillus

* Klein: Centralbl. f. Bakt., Orig., 1907, 44, p. 144.

† Flexner: Jour. Exper. Med., 1906, 8, p. 514.

‡ Dopter: Ann. de l'Inst. Pasteur, 1905, 19, p. 353.

§ Herter: "Bacterial Infection of the Digestive Tract," New York, 1907.

‖ Petruschky: Centralbl. f. Bakt., 1896, 19, p. 187.

morphologically and culturally, even to its growth on the Endo, Conradi-Drigalski, and malachite-green media. It has been found in feces and in water. The points of difference between it and the typhoid bacillus are: possession of one or more polar instead of many peritrichal flagella, more luxuriant growth on potato with a brown coloration, and distinct alkali production in mannite media and in milk or litmus whey. It fails to produce acid from glucose. The view has been advanced that B. fecalis alkaligenes is merely a form of B. fluorescens non-liquefaciens, which has completely lost the function of pigmentation; but Klimenko,* who studied a series of cultures from different sources, found the two organisms to be distinct both culturally and in their reaction to the agglutination test. The cultures of his series were not pathogenic or only slightly so for guinea-pigs, rats, and mice. Considerable attention was attracted to this organism by the assertion† that it and the typhoid bacillus were interconvertible, but further investigation has failed to confirm this claim, which seems to have been made on the basis of work with cultures not in a state of purity. Well-defined and constant differences separate the two bacilli.‡

* Klimenko: Centralbl. f. Bakt., 1907, 43, p. 755.

† Altschüler: Münch. med. Wchschr., 1904, 51, p. 868; Doebert: Arch. f. Hyg., 1905, 52, p. 70.

‡ Gaehtgens: Arch. f. Hyg., 1907, 62, p. 152.

CHAPTER XIX

THE BACTERIA OF HEMORRHAGIC SEPTICEMIA; BACILLUS PESTIS

The term hemorrhagic septicemia was applied by Hueppe in 1886 * to a group of highly fatal infectious diseases of the lower animals in which large and small hemorrhagic areas are found in the subcutaneous tissues, serous membranes, muscles and lymph-glands, and throughout the internal organs. In this class belong especially the affections described as swine plague (Ger., *Schweineseuche*), fowl cholera, and rabbit septicemia; with these is also to be ranked a disease of cattle described under a great variety of names (Wildseuche, Rinderseuche, Barbone, septic pleuro-pneumonia, pneumo-enteritis, etc.).

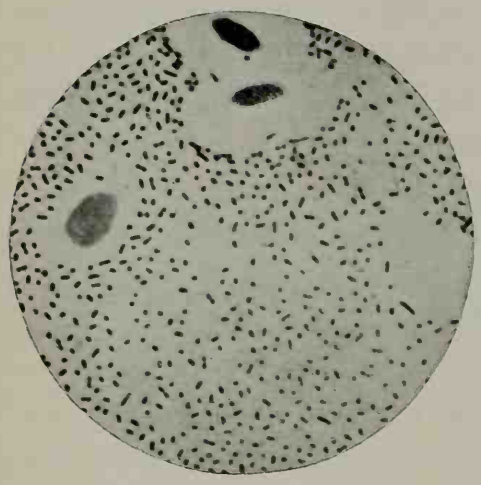


Fig. 77.—Bacillus of hemorrhagic septicemia in blood of a bird. Fuchsin stain (Kitt prep.) (Kolle and Wassermann).

The bacteria that are found in these widespread and important epizoötic diseases present many points of resemblance. They are short, non-motile bacilli, with a marked tendency to bipolar staining (Fig. 77). They are decolorized by Gram's method and do not form spores. Growth on gelatin is at best scanty, and liquefaction never occurs. On acid potato, as a rule, no growth results. The names of B. avisepticus, B. bovisepticus, and B. suisepticus have been bestowed upon the cultures obtained respectively from fowls, cattle, and swine. These cultures derived from different sources are very similar, and in most cases no material difference can be detected in morphologic and cultural characters. The

* Hueppe: Berl. klin. Wchnschr., 1886.

pathogenicity of the several strains is usually high, and, although variations in pathogenic power have been observed, most of the small laboratory animals and the common domestic animals succumb to inoculation. Fowls have been immunized against fowl cholera by cultures of the "bacillus of rabbit septicemia" (Kitt*), and Voges† has produced in fowls a disease resembling fowl cholera by feeding them with cultures of the swine plague bacillus. There are many other facts that speak for the very close relationship, if not the identity, of the organisms found in the various forms of hemorrhagic septicemia. The name Bacillus pleurisepticus has been suggested as a unifying designation. So far as known, this disease or group of diseases is not communicable to man. A bacterium closely related to the bacteria of hemorrhagic septicemia is B. pestis, the bacillus causing the plague, or "black death."

Bacillus Pestis

During the middle ages the plague prevailed extensively throughout Europe. The narrow, dirty streets and rat-infested dwellings of the walled towns, then becoming densely peopled, seem to have been highly favorable to the spread of the disease, and in some districts whole populations were carried off by the scourge. Hecker, a reliable authority, estimates that 25,000,000 persons, or one-quarter of all the inhabitants of Europe, perished in "The Great Mortality" or "Black Death" of the fourteenth century (1348–49). Few diseases have left so deep a mark on general literature. The Decameron of Boccaccio purports to be a collection of stories told by a company of ladies and gentlemen driven by the plague to take refuge in a country house outside the walls of Florence, and one of the most vivid descriptions of the plague ever written is from Boccaccio's pen. Defoe's famous "Journal of the Plague Year," although a fictitious narrative,‡ gives a realistic and essentially true picture of the devastation of London in 1665 by an outbreak of the dreaded "black death," in which 70,000 persons perished. Commerce and industry were then largely suspended and thousands of persons fled for safety to the open fields about London.

* Kitt: Kolle and Wassermann, Handbuch, 3, p. 560.

† Voges: Ztschr. f. Hyg., 1896, 23, p. 149.

‡ Defoe was only four years old in the year of the Great Plague.

For reasons that may be only partly conjectured the plague has had irregular periods of quiescence and recrudescence. Western Europe has been practically free from the plague since the middle of the eighteenth century, and the disease began its first great extension in modern times with its appearance in 1893 in Hongkong and 1896 in Bombay. During recent years the plague has caused terrible loss of life in British India. Official statistics show that in the period of 1896 to 1907 about 6,000,000 deaths were due to this disease. In October, 1899, a case was recorded at Santoz, Brazil; this is thought to be the first occurrence of the plague in the western hemisphere. Other cases have since been reported in and about San Francisco, in parts of Mexico, and in Central America.

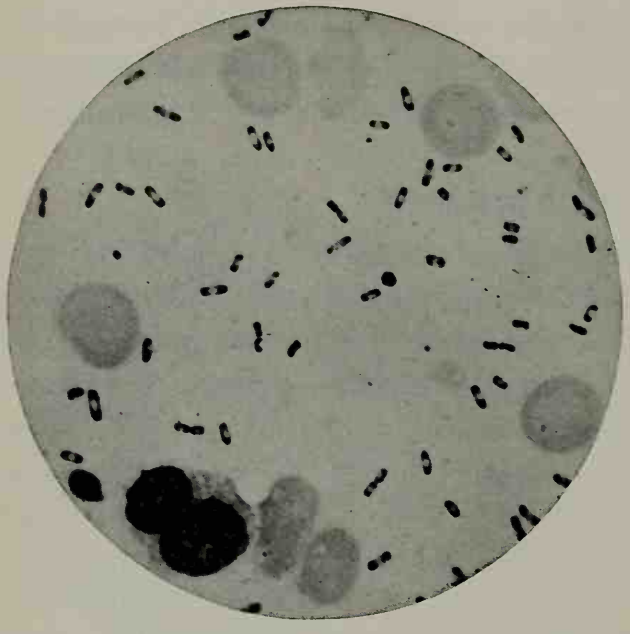


Fig. 78.—Bacillus pestis in smear from rat's liver, showing bipolar staining; × 720 (Wherry).

The specific bacillus of the plague (B. pestis) was discovered almost simultaneously by Yersin* and by Kitasato.† The germs are present in large numbers in the pulp of the young buboes, which is described by one writer as a "purée" of bacilli.

Morphology.—Cover-slip smears made from the organs of a plague victim show a short, plump bacillus with marked bipolar staining (Fig. 78). Wright's modification of the Romanowsky staining method ‡ is well adapted for staining the plague bacillus. The bacilli in body-fluids may occur in pairs, but long chains are rare. In broth cultures chains are the rule. Many morphologic variations,

* Yersin: Ann. de l'Inst. Past., 1894, 8, p. 662.

† Kitasato: Preliminary Notice of the Bacillus of Bubonic Plague, Hongkong, 1894; Lancet, 1894, 2, p. 428.

‡ Wright: Jour. Med. Res., 1902, 7, p. 138.

coccus shapes and large rods, are found. Pale and swollen involution forms, often reaching a gigantic size, are very common, and, like the other variations from the short, polar-stained rod, occur both in fresh preparations from plague corpses and in cultures. In films made from animal fluids or organs, a capsule is usually difficult to demonstrate, but on nutrient agar, capsular substance may be produced abundantly (Fig. 79) (Wherry *). By Gram's method decolorization occurs. B. pestis is not motile. Spores have never been observed.

Cultural and Biologic Characters.—Growth occurs on all the ordinary culture-media. Unlike most of the bacteria pathogenic for man, a temperature of 25° to 30° C. is more favorable than one of 37° C., and growth may even take place at a temperature as low as 4.5° C. Under all circumstances the colonies grow slowly and never attain a large size. Involution forms develop abundantly when the medium is dry. The addition of 3 to 4 per cent. of common salt to nutrient agar furnishes a medium that tends to produce involution forms so uniformly within the first twenty-four hours that the use of salt-agar has been recommended by Hankin and others as of diagnostic value. The colonies that develop on plates of ordinary nutrient agar and gelatin present a delicate, drop-like appearance with a round, granular center and a thin, granular, uneven margin (Fig. 80). Neither gelatin nor blood-serum is liquefied by the growth. On potato and in milk multiplication is

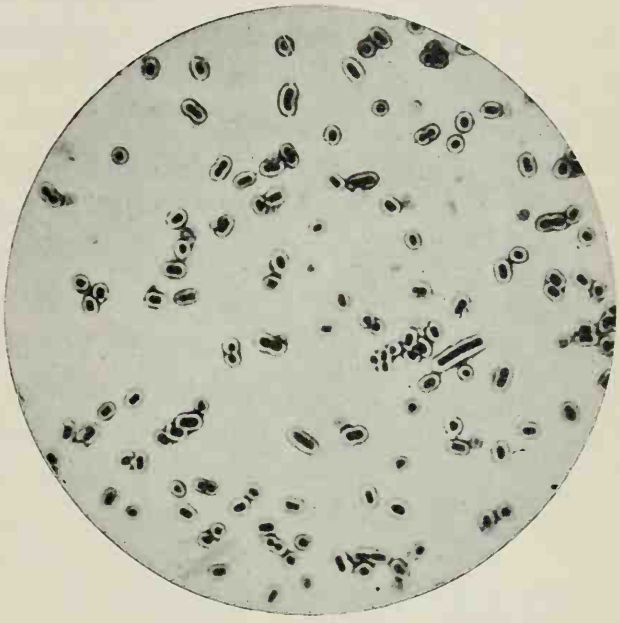


Fig. 79.—Bacillus pestis from agar culture, twenty-four hours, showing capsule; × 700 (Wherry).

* Wherry: Jour. Infect. Dis., 1905, 2, p. 577.

slow and scanty; milk is not curdled. No gas is produced in the presence of sugars, although a small amount of acid is formed from dextrose.

One of the most characteristic cultural features is observed in the growth in broth. When the surface of this medium is covered with a layer of oil * and flasks are left after inoculation undisturbed for five or six days, long, delicate filaments are formed which hang down from the surface into the depths of the clear broth, like the stalactites that depend from the roof of a grotto. Not all cultures of B. pestis show the stalactite growth in equal degree, and, on the other hand, a similar formation has been observed in cultures of other bacteria; the stalactite formation, therefore, while highly characteristic, especially when broth is seeded directly from fresh plague buboes, is not specific.

Toward various physiologic influences the plague bacillus does not exhibit marked resistance. Exposure to drying, particularly at the higher summer temperatures, speedily effects its destruction. The plague bacillus is also quite sensitive to the action of sunlight and chemical disinfectants. In general the life of B. pestis outside the animal body is precarious, and the bacillus seems to disappear speedily from soil, water, and buried cadavers.

Fig. 80.—Colony of bacillus pestis. Gelatin, forty-eight hours; × 150 (Wilson).

Obscurity still prevails regarding the toxic products of the plague bacillus. The results of experiments with broth cultures have been taken to indicate that the toxic element is not so closely associated with the cell substance as in the cases of cholera and typhoid bacteria, but is able to diffuse to some extent into the surrounding liquid, like the diphtheria and tetanus toxins. On the other hand, no antitoxic immunity has been obtained.

Modes of Transmission.—Filth and poverty have long been recognized as factors contributing to the persistence and spread of the plague. It would appear that what are known as medieval surroundings, whether in Europe in the fourteenth century or in

* "Ghee," a kind of clarified butter, is often used by bacteriologists in India for this purpose.

China and India in the twentieth, conduce to infection. Relatively close personal association is one of the conditions under which plague bacilli seem to be transmitted from the sick to the well. The sputum of plague patients suffering from the pneumonic type of the disease is highly infectious. The "infectious droplets" (p. 350) discharged in coughing also make the immediate neighborhood of the pneumonic plague patient dangerous to others.

There is evidence that in some epidemics of the plague, especially the bubonic type, transmission from one human being to another is not the way in which dissemination occurs. It was noted long ago by observers of epidemic plague that many outbreaks were accompanied by a remarkable mortality among rats. The discovery of the plague bacillus led to the further observation that the disease of rats was due to the same cause as that of man, and established the practically invariable association of rat plague and human plague. It is now known that rats* are highly susceptible to infection with B. pestis and may suffer spontaneously from epidemics under natural conditions. In San Francisco 14,184 rats were examined for plague between September 13, 1907, and January 14, 1908, and 192 were found infected. A chronic form of infection may exist among these animals, a circumstance that especially facilitates the dissemination of infection. Rats on shipboard are the means of carrying the disease from port to port, even when the human passengers remain perfectly healthy. Many observers have expressed the opinion on epidemiologic grounds that plague is primarily a disease of rats and that man is only an incidental victim. In consequence of these relations the possible modes of conveyance of plague bacilli from rat to man have become a subject of peculiar interest. Both the feces and the urine of plague-infected rats sometimes contain plague bacilli, and it might be thought that contamination of the surroundings could lead either to cutaneous infection or to infection through the alimentary tract. Experiments † have shown, however, that close and continuous

* At least three species, *Mus dekumanus*, the common sewer-rat, *Mus rattus*, the black house-rat and the ship-rat, and *Mus alexandrinus*, the Egyptian rat, are known to be infected.

† Report on Plague Investigation in India, Jour. of Hyg., 1906, 6, pp. 422–536; 1907, 7, pp. 323–476, and 694–985.

contact of plague-infected animals with healthy animals does not give rise to an epizoötic among the latter, *provided fleas are rigorously excluded.* The share of fleas in carrying infection from rat to rat and from rat to guinea-pig has been established by convincing experiments. The blood of plague-infected rats often contains enormous numbers of plague bacilli, as many as 100,000,000 per cubic centimeter having been found. Rats freed from fleas do not become infected by mere contact with plague-infected animals. Monkeys, guinea-pigs, and healthy rats, on the other hand, may contract the plague if they are brought into the neighborhood of flea-infested plague rats. In the reports of the plague investigation in India the following experiment with monkeys is recorded. Two monkeys were placed in similar cages, so designed that fleas could not get in from the top, and the cages put into a flea-infested animal house where three guinea-pigs had died from plague inoculation a few days previously. One monkey-cage was surrounded by a layer of sticky fly-paper six inches wide, it having been found that the leap of which a rat flea is capable is not greater than about five inches; the other monkey was not so protected. After two nights in the animal house the cages were removed. Two fleas were caught on the unprotected monkey and five were found stuck on the fly-paper protecting the other monkey. The unprotected monkey developed a typical case of plague, while the monkey that had been surrounded by fly-paper remained healthy. Further experience in the experimental production of plague epidemics among animals has entirely confirmed these results.

It is possible to infect rats by feeding them with the carcasses of their plague-infected comrades. In rats infected in this way mesenteric buboes are most frequent. Cervical buboes, on the other hand, preponderate in naturally infected rats, in guinea-pigs infected by being placed in a plague-infected house, and in rats and guinea-pigs artificially infected with fleas. The examination of one series of 5000 naturally infected rats showed not a single case of mesenteric bubo. The conclusion seems justified, therefore, that rats in nature are not infected by feeding upon plague-infected material, but are infected, as a rule, through the agency of fleas.

There is much to support the view that the plague may be communicated to man also by the bite of the rat flea. The commonest

rat flea, except in Northern and Central Europe, is *Pulex cheopis* (Rothschild), and there is evidence that this species will readily bite man. When abundant, it will bite man in the presence of its natural host. Rat fleas have been found in large numbers on the legs of men who entered for a short time the rooms of a plague-infected house. The particular danger that is known to attach to sleeping in a plague-infected house is explicable from this standpoint. Ashburton Thompson,* who has made a careful study of four outbreaks of the plague at Sydney, concludes that the epidemiologic data in that locality harmonize best with the view that the rat flea transmits the disease from rats to man. Gotschlich † has found that in Egypt the winter plague epidemics are of the pneumonic type and are spread through human agency, while the summer plague cases are of the bubonic type and are due exclusively to rat infection. Kitasato has observed a similar seasonal incidence in Japan.

In California the native ground squirrels have proved highly susceptible to pest infection and, probably through the agency of these animals, the disease had in 1909 spread over a considerable area. Cases of plague in man due to squirrel infection have been reported.‡

Pathogenesis for Man.—The belief that the bacillus called B. pestis stands in direct causal relation to plague received experimental confirmation from an accidental laboratory infection that took place in Vienna in October, 1898. A commission sent by the Vienna Academy of Sciences in January, 1897, to study the plague in Bombay, returned to Vienna some three months later bringing much material for observation and experiment. After the work with pure cultures of B. pestis had been in progress for some time, the man who cared for the animals under experimentation is supposed, when under the influence of drink, to have neglected some essential precaution. At all events he became infected; no other case of the plague existed in Vienna at the time. The physician, himself a member of the commission, and the two nurses who cared

* Thompson, Ashburton: Jour. of Hyg., 1906, 6, p. 537.

† Gotschlich: Festschrift f. R. Koch, Jena, 1903.

‡ See Special Report on Plague on the Pacific Coast, Jour. Amer. Med. Assoc., 1907, 49, p. 2000; also McCoy and Wherry; Jour. Infect. Dis., 1909, 6, p. 670.

for this patient, all contracted the infection, and the physician and one nurse died.

Plague in man appears most commonly in two forms: the bubonic or glandular plague and plague pneumonia. In the bubonic type the symptom-complex is characteristic, and diagnosis on clinical grounds is relatively simple. From the buboes,* which may be either primary or secondary, bacilli may pass over into the blood; in fatal cases the bacteria often multiply in the blood extensively. A primary plague septicemia can also probably occur. There are sometimes subcutaneous hemorrhages. During the plague epidemics in the middle ages such hemorrhages seem to have been more frequent than at present, and the dark spots to which they give rise were the origin of the popular name of "the black death."

Plague pneumonia is usually fatal. In this variety of the plague the sputum may contain enormous numbers of plague bacilli. As a direct means of spreading contagion from man to man, plague pneumonia is by far the most dangerous type.

A primary infection of the skin with the plague bacillus sometimes occurs (cutaneous plague), but does not seem to be common. Cases of mild plague, the so-called *pestis minor* (compare "walking typhoid"), are met in some epidemics. The occurrence of intestinal plague in man has never been clearly established.

The entrance of the plague bacillus into the body is probably usually by way of the skin, the buboes originating in the neighborhood of the point of entrance. Infection through the tonsils and respiratory tract, especially from cases of pneumonic plague, can also take place. Infection by swallowing, on the other hand, if it occurs at all, is extremely rare.

Pathogenesis for the Lower Animals.—Many rodents, such as rats, mice, and guinea-pigs, are very susceptible to the plague. In California, however, from 20 to 70 per cent. of the full-grown rats (Mus norvegicus) are refractory when inoculated with highly virulent cultures. The California ground squirrels are much more susceptible than the rats. Certain species of monkeys are extraordinarily sensitive to subcutaneous inoculation, $\frac{1}{10000}$ to $\frac{1}{1000}$ of a loopful of an agar culture being sufficient to produce a fatal septicemia. Both monkeys and rodents develop buboes and ex-

* Inflamed and swollen lymphatic glands.

hibit other features common to the plague in man. Rats and guinea-pigs may be infected by feeding, especially when large numbers of bacilli are administered. Cats are susceptible to artificial infection. Dogs, swine, cattle, and horses can be infected by injecting them with large doses, but apparently do not contract the disease spontaneously under natural conditions.

Owing to the close relation existing between plague in rats and in man the phenomena of rat infection have been especially studied. The diagnosis of plague infection in rats is practically important, and special procedures are in use for this purpose.* Recent observers maintain that for purposes of diagnosis naked-eye examination by a competent observer is more satisfactory than microscopic examination alone.† Ledingham,‡ in observations upon spontaneous cases of rat plague, found that in some animals bacterial invasion of the spleen and liver is pronounced and is accompanied by extensive hemorrhages and congestion of the pulp sinuses and liver capillaries. In others, definite abscess formation in the spleen is far more frequent, while in the liver focal necroses may be very numerous. Externally the liver and spleen, especially the former, frequently present a granular and mottled appearance which is quite characteristic. Typical buboes are present in the great majority of cases (85 per cent.). Subcutaneous and internal hemorrhages are very common. In the experience of the investigators of rat plague in India an abundant, clear pleural effusion is an important diagnostic sign.

Protective Inoculation and Immunity.—A method of protective inoculation against the plague devised by Haffkine § has been extensively practised in India. As usually prepared, "Haffkine's prophylactic" consists of broth cultures in which repeated crops (five to six) of the stalactite formation have been obtained by successive inoculations, shakings, and reinoculations. After about six weeks the culture is killed by warming the flask of broth in the water-bath for one hour at 65°. The usual dose of the prophylactic is about 2 c.c., but larger quantities may be given, and the dose is

* See Kister, Centralbl. f. Bakt., 1906, 41, Orig., p. 780.

† Wherry, Walker and Howell: Jour. Am. Med. Assoc., 1908, 50, p. 1165.

‡ Ledingham: Jour. of Hyg., 1907, 7, p. 359.

§ Haffkine: Brit. Med. Jour., 1897, 1, p. 424.

generally proportioned to the age and size of the individual. Considerable success has attended its use: the proportion of vaccinated persons attacked is smaller than that of the unvaccinated in the same population, and those vaccinated persons who do contract the disease suffer from it in a comparatively mild form. The German Plague Commission has recommended an essentially similar procedure, namely, the injection of a two-day agar culture killed by heat. Kolle and Otto * have shown that in animal experimentation much better results are obtained with attenuated cultures than with killed bacteria, and Strong † has found on applying this method to man that a high degree of immunity to the plague may be produced by inoculation of an attenuated strain. Hueppe and Kikuchi ‡ have reported favorable results in the active immunization of animals, from the use of the peritoneal exudates obtained from guinea-pigs that had been inoculated intraperitoneally with plague bacilli.

Yersin and Roux § have produced a serum that possesses some curative properties by injecting horses first with killed cultures, then with living cultures. The Yersin serum has considerable bactericidal power, but experiments have shown that its curative action is not due solely to bacteriolysis. There is evidence that it facilitates phagocytosis. No antitoxic effect has been observed. Many investigators have failed to secure favorable results with this serum, but, in the epidemic of plague at Oporto, Calmette and Salimbeni || employed it with success.

* Kolle and Otto: Ztschr. f. Hyg., 1903, 45, p. 512; 1904, 48, p. 399.

† Strong: Phil. Jour. of Sci., 1906, 1, p. 181.

‡ Hueppe and Kikuchi: Centralbl. f. Bakt., 1905, 39, p. 610.

§ See Metchnikoff: Ann. de l'Inst. Past., 1897, 11, p. 737.

|| Calmette and Salimbeni: Ann. de l'Inst. Past., 1899, 13, p. 865.

CHAPTER XX

THE INFLUENZA BACILLUS (BACILLUS INFLUENZÆ)

Although attention has been especially drawn to influenza in modern times by the widespread epidemic of 1889–90, the disease is one that has long prevailed more or less extensively in various parts of the world, and is known to have swept over medieval Europe from time to time in great epidemic waves. The "sweating sickness" of the fifteenth century was perhaps a form of influenza.*

The discovery of the influenza bacillus was announced in January, 1892, by three independent observers—Pfeiffer, Canon, and Kitasato. The observations of Pfeiffer † proved to be particularly complete and accurate, and in the main have been confirmed by subsequent investigation.

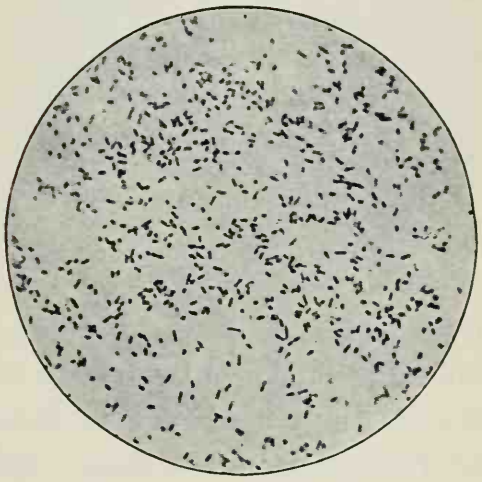


Fig. 81.—Bacillus influenzæ; × 1000 (Král).

Morphologic and Cultural Characters.—The influenza bacillus is one of the smallest known pathogenic bacteria, rarely exceeding 1.5 μ in length and 0.3 μ in thickness. The ends of the cell are rounded, no capsule is present, and spores have never been observed: the bacillus is non-motile (Fig. 81). Many stains show a marked tendency to produce threads and other anomalous forms in cultures. Staining is best effected with a dilute (1:10) solution of carbol-fuchsin for five to ten minutes; Gram's stain is not retained. Cultures of this organism were first obtained by Pfeiffer upon blood-agar, prepared either with human blood or the blood of other animals, such as the guinea-pig or pigeon; and blood-agar remains to this day a practically indispensable medium for growing the

* Hamer: Lancet, 1906, 1, p. 655.

† Pfeiffer: Dtsch. med. Wchschr., 1892, 18, p. 28; Ztschr. f. Hyg., 1892, 13, p. 357.

influenza bacillus. The hemoglobin of the blood is the essential ingredient, since growth occurs just as abundantly on agar smeared with a solution of hemoglobin as on agar prepared with whole blood. When the surface of blood-agar is smeared with influenza sputum and incubated at 37° C., with free access of oxygen, minute, rounded, discrete, translucent colonies become visible in about eighteen hours. Transplanted to ordinary agar, no development usually results, but on blood-agar further colony formation occurs. The colonies at the largest may reach the size of a small pinhead. If the culture be contaminated with other organisms, especially Staphylococcus aureus, the influenza colonies are considerably larger, more opaque, and of a grayish-white color. Even under favorable conditions artificial cultures soon die out, and in order to preserve vitality subcultures must be made on hemoglobin agar every four or five days; in this way the stock may be maintained indefinitely. Toward external influences the influenza bacillus shows little resistance. Desiccation is quickly fatal: a pure culture suspended in water and then dried on silk threads loses its vitality within twenty-four hours; in dried sputum life is maintained somewhat longer, but not, as a rule, beyond forty-eight hours. The bacilli are readily killed by disinfectants. All the evidence indicates that the influenza organism does not survive long, much less multiply, outside of the human body. The germ is therefore rarely, if ever, transmitted for long distances through the air.

Pathogenesis for Man.—The chief reason for believing that the so-called influenza bacillus bears a causal relation to the disease is its presence in great abundance in the secretions from the mouth and nose of influenza patients. In acute uncomplicated cases it may even be found in pure culture, and a probable diagnosis may be made by a skilled observer directly from the microscopic examination of stained sputum (Fig. 82). In many cases, however, the bacillus is associated with the pneumococcus or some other micro-organism, and recourse must be had to cultural methods. While in the earlier stages of the disease large masses of bacilli are seen lying free, in the later stages and in chronic cases fewer free bacilli are found, and a larger number are embedded within leukocytes.

As a rule, the invasion of the body by the influenza bacillus is confined to the air-passages. The lung tissue is frequently affected, a form of pneumonia, usually of the lobular type, being the result.

The pneumonic process has been stated by some observers to be characteristic, but more often it cannot be distinguished clinically or histologically from the pneumonia produced by the pneumococcus. Mixed infections in which the influenza bacillus is accompanied by streptococci, pneumococci, and other bacteria are by no means infrequent. There is no evidence of the multiplication of influenza bacilli in the blood, and when found at all, their presence in the blood is probably due to accidental entrance from infected tissue.

The symptoms that accompany influenza—a disease clinically protean—are sometimes classed as catarrhal, gastric, intestinal, nervous, etc., and are probably to be referred to the selective action of the toxin in different individuals, rather than to localization of infection. In inflammation of the middle ear, however, and of the meninges, influenza bacilli are sometimes found in the exudate. The presence of influenza bacilli, or of organisms resembling them, in the sputum of consumptive persons has been often observed, and it has been noted that consumptives seem particularly liable to attacks of influenza. Influenza bacilli have also been found in the sputum and the nasal secretion of patients suffering from measles and some of the other acute exanthemata. The full significance of this is not known. A special variety of "intestinal influenza" has been described by some writers, but it is still uncertain to what extent local infection is responsible for the symptom-complex so designated. The swallowing of bronchial secretion might conceivably give opportunity for intestinal localization. Influenza sometimes exists in a chronic form, in which the bacilli appear in the nose and throat secretions for months. During periods when influenza does not prevail in epidemic form, influenza bacilli are found in the sputum in certain cases of acute and chronic respiratory disturbance. The patients do not often present the typical symptoms of influenza, and it is uncertain whether the

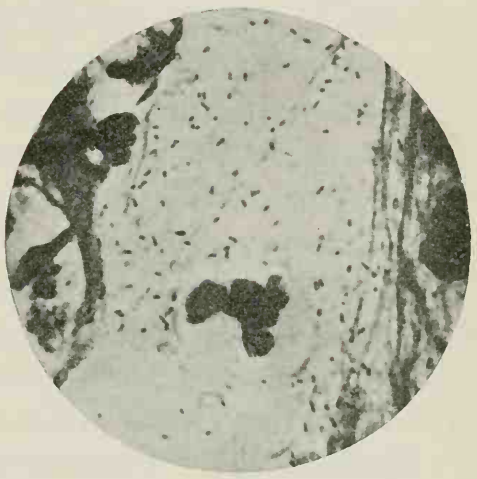


Fig. 82.—Bacillus influenzæ in sputum. Fuchsin stain. Beck prep. (Kolle and Wassermann).

influenza bacillus in such cases is to be looked upon as a primary or secondary invader. The micro-organism is also found in a considerable proportion of healthy persons. In the specific disease of whooping-cough a bacillus to all appearances identical with the influenza bacillus occurs in large numbers. These facts conspire to throw some doubt on the etiologic relation that Pfeiffer's bacillus bears to the specific disease of influenza. Possibly the so-called influenza bacillus merely accompanies or follows in the train of the true and unknown causal agent. Lord* found that 25 per cent. of unselected cases with cough and expectoration, during an inter-epidemic period, showed this organism present in overwhelming numbers, while during an epidemic of influenza only 15 per cent. of cases with the clinical features of influenza showed the bacillus. In any event the assumption that Pfeiffer's bacillus is the cause of influenza must be made to square with the facts of epidemic prevalence by supposing either that races of B. influenzæ of high virulence sometimes arise, or, what is quite unlikely, that waves of enhanced susceptibility sweep over large bodies of people, or that communication of infection is in some way facilitated. There is no doubt that further evidence is desirable.

Epidemiology.—Assuming that Bacillus influenzæ is the cause of influenza, its sensitiveness to drying renders dust infection highly problematic. On the other hand, its presence and persistence in the nasal and bronchial secretions of convalescents and chronic cases, in the sputum of consumptives, and even in the mouth and nose of healthy persons who have been in contact with influenza patients, affords a ready and plausible explanation of many of the phenomena of distribution and transmission. The fine droplets expelled from the respiratory passages in the act of sneezing, coughing, or talking constitute a source of danger as real here as in the case of tuberculosis; this is perhaps one of the chief, if not the chief, means by which the disease is spread.†

* Lord: Jour. Med. Res., 1908, 19, p. 295.

† President Eliot (Science, June 1, 1906, p. 837) has brought to notice the following observation by Benjamin Franklin: "I have long been satisfied from observation, that besides the general colds now termed influenzas (which may possibly spread by contagion, as well as by a particular quality of the air), people often catch cold from one another when shut up together in close rooms and coaches, and when sitting near and conversing so as to breathe in each other's transpiration; the disorder being in a certain state."

The universality of travel and other intercourse in modern times would help to account both for the occurrence of apparently sporadic cases and for widespread or sudden epidemics. Of obscure causes that might affect the virulence of the germ or the susceptibility of large groups of individuals nothing is known.

Effect on Animals.—Inoculation of the species of animals ordinarily used in experimentation has not, for the most part, given important results. Only monkeys and rabbits exhibit reactions that are in any degree significant. In these animals symptoms suggestive of those of influenza are evoked by intravenous injections (rabbits) or intrapleural injections (monkeys) (Pfeiffer). The effects obtained by the use of living cultures and cultures killed with chloroform are very similar, indicating that the injury to the animals in these experiments is not to be attributed to a true infection, but rather to the action of the bacterial products. No genuine generalized infection has been produced.

A slight increase in the resistance of animals inoculated with non-fatal doses has been observed by several investigators, and the serum of such immunized animals possesses some degree of protective, but no curative power. This stands together with the fact that no soluble toxins are present in cultures. Agglutinins are found in the bodies of immunized animals, but the agglutinating value of the serum is not usually high (1: 500) and is inconstant. In man there is some evidence that an attack of influenza imparts a transient immunity.

The Koch-Weeks Bacillus.—A small bacillus, first observed by Koch * in 1883 in a series of eye-inflammations in Egypt, was successfully cultivated by Weeks † in New York in 1890, and is now recognized as the cause of a world-wide and highly contagious form of conjunctivitis (Fig. 83). One important difference between the Koch-Weeks bacillus and the influenza bacillus is that the latter depends for satisfactory growth upon the presence of hemoglobin in the culture-medium, while the Koch-Weeks bacillus is not restricted to hemoglobin media. Another distinction is that animal inoculations with the Koch-Weeks bacillus have thus far given entirely negative results. Morphologically, the two organisms are very

* Koch: Arb. a. d. kais. Gesund., 1887, 3, Anlagen, p. 62.*

† Weeks: N. Y. Med. Rec., 1887, 31, p. 571.

closely similar, the Koch-Weeks bacillus being on the average somewhat longer. They are alike also in their staining reaction.

Growth may occur on ordinary nutrient agar at 37° C., but most success is obtained with serum-agar, or a mixture of glycerin-agar and ascitic fluid (2 : 1). The colonies appear as minute, projecting, transparent dots, which tend to become confluent; they never attain a large size and are easily detached from the medium. The bacilli possess slight powers of resistance, and there is little reason to suppose that dust is a common means of conveying infection. Direct contact with infective material through the medium of hands, towels, handkerchiefs, etc., must rather be considered the usual mode of conveyance. Flies may also be concerned in transmission. A peculiar form of hand infection due to an organism probably identical with the Koch-Weeks bacillus has been described by McDill and Wherry.*

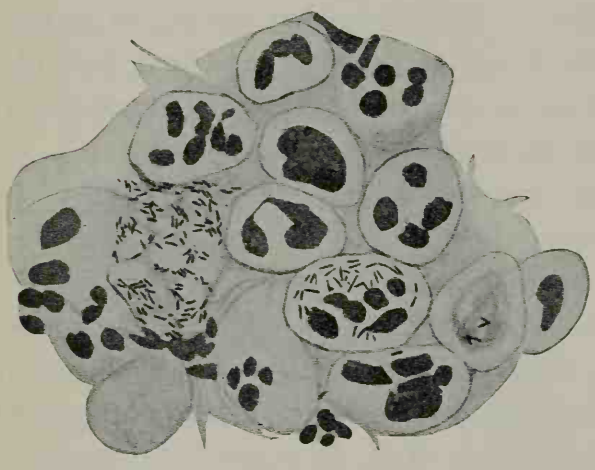


Fig. 83.—Koch-Weeks bacillus in conjunctivitis; × 900 (Axenfeld, Kolle and Wassermann).

"Pseudo-influenza Bacilli."—Several observers have described bacilli met with in pathologic conditions in man and other animals, which they have recognized as very similar to the influenza bacillus, but which they are inclined to regard as in a measure distinct. The main differences that have been recorded are slight. The pseudo-influenza bacillus is said to be somewhat larger and to show more of a tendency to grow out into long threads. The establishment of a separate group of "pseudo" bacilli on the basis of such characters seems of doubtful expediency.

Influenza-like Bacilli in Whooping-cough.—A number of observers (Spengler,† Jochmann and Krause,‡ Davis,§ and others)

* McDill and Wherry: Jour. Infect. Dis., 1904, 1, p. 58.

† Spengler: Deut. med. Wchnschr., 1897, 23, p. 830.

‡ Jochmann and Krause: Ztschr. f. Hyg., 1901, 36, p. 193.

§ Davis: Jour. Infect. Dis., 1906, 3, p. 1.

have found in the sputum of whooping-cough patients a bacillus which, morphologically and culturally, is identical with the influenza bacillus. This organism is most abundant during the spasmodic stage, but is also found throughout the course of the disease. It cannot be differentiated by present methods from the organism found in influenza or from organisms that occur in a variety of throat affections and are occasionally present in normal throats. Davis concludes, as a result of a careful comparative and experimental study, that the evidence at hand will not permit a definite statement for or against the specificity of this organism for whooping-cough.

CHAPTER XXI

THE PATHOGENIC ANAËROBES

Anaërobic bacilli constitute a class by themselves in the sense that the methods used at present for the study of these organisms reveal numerous and important points of resemblance, but no deep-seated differences.

The most thoroughly investigated disease due to an anaërobe is lockjaw or tetanus. (Ger., *Der Starrkrampf, Der Tetanus;* Fr., *Le Tétanos.*)

Bacillus Tetani

The tetanus bacillus was first described in 1884 by Nicolaier,* who observed it in the pus taken from mice and other animals that had died after subcutaneous inoculation with small quantities of soil. He did not, however, succeed in inducing the bacillus to grow except in mixed cultures. Kitasato,† by the use of special anaërobic methods, first obtained B. tetani freed from other microbes (1889), and was able to reproduce the specific disease by means of pure cultures.

Morphology and Physiology.—The individual tetanus bacillus is a rather long, slender rod with rounded ends; sometimes long threads occur, especially in old cultures. Spore formation begins in about twenty-four to thirty hours at 37° C., and in eight to ten days at room temperature. The spore is generally spherical, is located at one end, and is from two to three times the diameter of the rod. The drumstick appearance of the tetanus bacillus in this stage of spore formation is quite characteristic (Fig. 84), The bacilli stain readily with the ordinary dyes and retain the stain when treated by Gram's method. They possess a large number of peritrichal flagella, and have the power of slight independent movement.

It is difficult even for experienced workers to isolate the tetanus

* Nicolaier: Inaug. Diss., Göttingen, 1885.

† Kitasato: Ztschr. f. Hyg., 1889, 7, p. 225.

bacillus in pure culture. The inoculation of suspected material into mice or white rats is a desirable preliminary step. The method of heating soil, pus, or mixed cultures to 80° C. for one-half hour (Kitasato) simplifies isolation by destroying the vegetative forms of other bacilli that are present, but may still leave the spores of the tetanus bacillus badly mixed with those of other anaërobic bacteria. Isolation by this method is most likely to succeed when the material contains a high proportion of tetanus spores compared with the spores of other anaërobes, as may be the case in the pus produced in animals subcutaneously inoculated with a small quantity of manured soil or street dust.

Under ordinary conditions the tetanus bacillus is a strict anaërobe. If a large number of bacilli, however, are introduced into the culture-medium, as in the transfer of a pure culture, growth will occur under imperfectly anaërobic conditions. In mixed cultures also the tetanus bacillus can thrive even when air is admitted, a phenomenon attributed to the exhaustion of the oxygen-supply by the associated aërobic bacteria or their products. A certain degree of tolerance to the presence of oxygen can be brought about gradually in pure cultures.

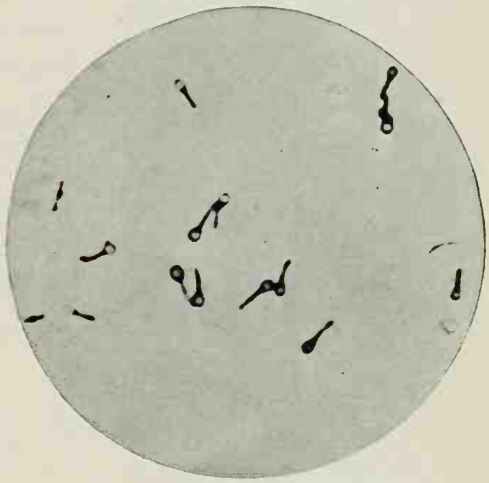


Fig. 84.—Bacillus tetani showing spores. Pure culture on agar. Fuchsin stain (Kolle and Wassermann).

Growth on gelatin is slow, the colonies first being visible in about three days; under a low power of the microscope filaments are observed radiating from a central core; the gelatin is slowly liquefied. The appearance is not unlike that of Bacillus subtilis. Reducing substances, such as glucose (15 per cent.) or sodium formate (HCO_2Na), are often added to the culture-medium to facilitate growth. In agar stab-culture the growth resembles a fir tree with delicate twigs and branches (Fig. 85). Blood-serum is liquefied by the growth. A small amount of gas, chiefly a mixture of sulfuretted hydrogen and carbon dioxid, is produced in all media, especially

in the presence of carbohydrates. Tetanus cultures have a disagreeable and characteristic odor. Growth occurs in milk, and coagulation with acid reaction takes place.

Pathogenesis for Man.—The disease of tetanus or lockjaw presents some rather singular features. The tetanus bacillus is one of the most common and widely distributed of all pathogenic bacilli; it is found in cultivated soil and in street dust, and is abundant in the droppings of the horse and some other animals. This widespread occurrence of the tetanus bacillus seems at first glance out of harmony with the relatively infrequent occurrence of tetanus infection, but the explanation is found in the circumstance that mere introduction of the bacillus into the body is not sufficient to produce a case of tetanus. The bacilli must find favorable conditions for proliferation at the site of their penetration or lodgment, otherwise infection will not take place. In animal experiments bacilli or spores which have been freed from toxin and introduced in pure culture and in moderate numbers into the tissues cannot germinate, and are hence innocuous. On the other hand, simultaneous inoculation with common saprophytes, such as B. prodigiosus, or with chemical substances, such as lactic acid, enables the bacilli to proliferate and toxin production to occur. Infection of man appears most likely to result when the tissues suffer considerable injury at the time the tetanus bacillus is introduced, and much foreign matter is forced far into the wound. Common experience has taught that tetanus develops most frequently in connection with punctured or contused wounds. In addition to the cases of tetanus that follow in the wake of a great battle, and those

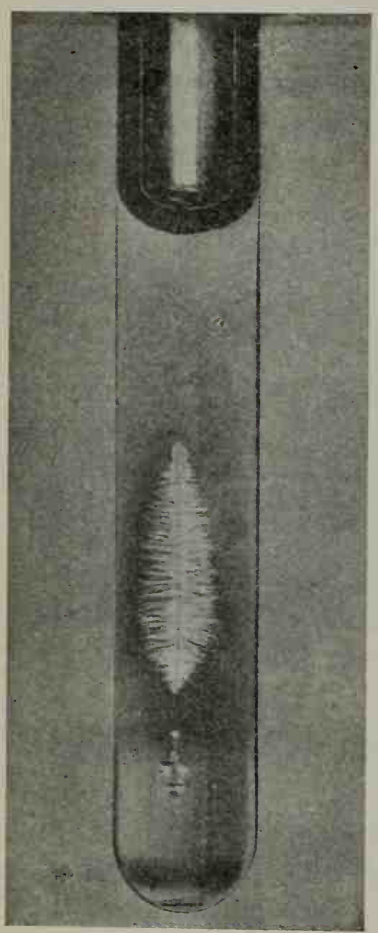


Fig. 85.—Bacillus tetani, gelatin stab-culture, six days (Fränkel and Pfeiffer).

that occur from septic midwifery (tetanus neonatorum*), there are others whose sources are as well known. Such are the infections that occur in stablemen and other persons whose occupation brings them in frequent contact with the dung of animals rich in tetanus spores, the "toy pistol tetanus" arising from the lacerating wounds of the blank cartridge, the tetanus following hemostatic injection of gelatin,† and the rare infections resulting from the use of impure vaccine lymph and similar biologic products.‡ All wounds of a nature likely to provoke tetanus call for radical treatment by cleansing and drainage, and for the administration of antitoxic serum, if necessary, under anesthetics.

A case of tetanus in man is usually the result of the subcutaneous introduction of tetanus spores simultaneously with a considerable amount of foreign matter which, as a rule, includes saprophytic bacteria. Visible changes in the tissues are not marked. Although there is sometimes suppuration, the local reaction is often insignificant. The specific bacillus, while able to multiply to some extent, remains localized and does not spread throughout the body. The symptoms of this disease, among which may be mentioned the

* From infection at the umbilicus. This form of tetanus is especially rife among the negroes of the southern States and other races living under unhygienic conditions. (See Anders and Morgan, Jour. Amer. Med. Assoc., 47, 1906, p. 2083.) There is one famous case of a small island near Iceland with a total population of about 200, in which 185 new-born children perished from this form of tetanus in the space of twenty-five years.

† Gelatin is generally made from the bones or hides of domestic animals. The spores of the tetanus bacillus which are abundant in the surroundings of these animals are in some cases able to survive the process by which gelatin is manufactured. (See Bull. No. 9, Hygienic Lab. Public Health and Marine Hospital Service.)

‡ McFarland: Jour. Med. Res., 1902, 7, p. 474. An unfortunate outbreak of tetanus occurred in 1902 at Mulkowal in British India during the course of a series of inoculations of Haffkine's plague prophylactic. In a total of 107 persons given the prophylactic, 19 developed symptoms of tetanus and died. All the affected individuals were inoculated with fluid from the same bottle. The source of infection is unknown. It is possible that the contents of the bottle were infected, but serious error in technic also seems to have been committed at the time of the inoculation. (Jour. Trop. Med., and Hyg., 1907, 10, p. 33; The Practitioner, 1907, 78, p. 796.) Theobald Smith (Jour. Amer. Med. Assoc., 1908, 50, p. 929) has laid special emphasis on the necessity of avoiding the introduction of the highly resistant tetanus spores into materials used in the preparation of antitoxins, vaccines and other biologic products used for subcutaneous injections.

disturbance of the central nervous system, as evinced in the characteristic muscular spasms, depend upon the absorption of the toxic products of the bacilli rather than upon the presence of the bacilli themselves. It has been shown by Meyer and Ransom * that the tetanus toxin is absorbed by the end organs of the motor nerves and travels to the ganglion cells of the central nervous system, not by way of the blood or lymph-channels, but along the axis-cylinders of the peripheral nerves. The time consumed in this passage represents the larger part of the long incubation period. The toxin may circulate for a time in the blood, but the only path to the central nervous system lies along the axis-cylinders of the motor nerve tracts. A cut nerve takes up the toxin very slowly and a degenerate nerve not at all. Section of the spinal cord prevents the toxin from reaching the brain. Meyer and Ransom believe that the spinal ganglion of the sensory nerve presents a barrier to the advance of the toxin along this channel, and that for this reason sensory nerves are unable to conduct the toxin. The remarkable excitation of the motor cells of the spinal cord that is observed in tetanus is unaccompanied by characteristic lesions.

Pathogenesis for Other Animals.—In the horse tetanus is not a rare affection, the symptoms and course of the disease being similar to the disease in man. Cattle and sheep are less commonly affected. Experimentally, tetanus can be produced in mice and in guinea-pigs by inoculation of spores especially when borne upon splinters of wood, and also by injection of toxin. Animals that are naturally immune to infection with living tetanus bacilli, such as birds, can be killed by large doses of toxin. The feeding of animals with tetanus bacilli or spores is without effect. Tetanus differs from most infectious diseases in that the diseased animal is not an appreciable factor in the spread of infection. The normal horse probably distributes tetanus germs quite as widely and freely as a horse sick with tetanus. At best the parasitic capabilities of the tetanus bacillus are slight; the germ is naturally adapted for a saprophytic existence.

The Tetanus Toxin.—A broth culture of the tetanus bacillus grown under strictly anaërobic conditions is usually highly toxic;

* Meyer and Ransom: Archiv. f. exper. Path. u. Pharm., 1903, 39, p. 369.

0.000005 c.c. or less can be fatal to a mouse weighing 10 grams. The toxin is highly unstable, being destroyed in aqueous solutions by exposure to light, heat, and chemical action, and also being inclined to lose its strength rapidly when a tetanus culture is allowed to stand under ordinary conditions. When it is to be used in experimental work it is advantageously precipitated and stored in a dry condition.

Ricketts* thus describes his method of preparing tetanus toxin from a broth culture. After a growth of nine days the culture was passed through Pukal filters, placed in large moisture dishes, and an excess of ammonium sulfate added;† the dishes were then placed in the thermostat overnight. The brownish scum which had formed by this time was skimmed off, placed between hardened filter-papers, and the excess of moisture pressed out. Still more fluid and ammonium sulfate were got rid of by subjecting the precipitate to very high pressure in a pressure machine. The precipitate, now in the form of solid cakes, was dried over sulfuric acid and eventually pulverized. It is preserved over sulfuric acid in the ice-chest and in the dark. For use a 0.2 per cent. solution of the precipitate was made in 0.85 per cent. sodium chlorid solution, and the doses used are expressed in cubic centimeters of this solution. The original fatal dose for white mice of about 15 grams weight was 0.000007 c.c. per gram of mouse; death occurred in four to five days.

Toxin preserved in this way undergoes little or no deterioration. The susceptibility of different animals to the tetanus toxin varies considerably; it is estimated that the horse is twelve times as sensitive as the mouse and 360,000 times as sensitive as the fowl, measured by the fatal dose per gram of body-weight. An incubation period is always observed, and this cannot be shortened beyond a certain minimum limit—in the mouse, eight hours—even with large doses.

The tetanus toxin possesses a strong affinity for the cells of the central nervous system, as evidenced by the now classic experiment of Wassermann and Takaki.‡ These investigators showed that a mixture of tetanus toxin and brain-substance can be injected into an animal without producing any toxic effect, the toxin apparently entering into so firm a combination with some ingredient of the nervous matter that it is powerless to affect the living organ-

* Ricketts: Jour. Infect. Dis., 1906, 3, p. 116.

† One-half more than the quantity of broth would dissolve at room temperature.

‡ Wassermann and Takaki: Berl. klin. Wchnschr., 1898, 35, p. 5.

ism. As pointed out elsewhere (p. 153), this fact is regarded as strongly supporting the receptor theory of antitoxin production. Not only the central nerve-cells, but to some extent other tissue cells, are able to bind tetanus toxin. Subcutaneous inoculation is less likely to result fatally than direct inoculation into nerve tissues, for the reason that in the former case the cells of the liver, kidney, connective tissues, etc., anchor the tetanus toxin and prevent it from reaching the highly sensitive nerve-cells. The exquisite susceptibility of an animal like the guinea-pig to tetanus toxin is perhaps correlated with the inability of the non-nervous tissues to bind the poison, thus leaving the toxin free to make its way to the central nervous system.

That tetanus toxin may sometimes circulate in the blood of an animal in considerable quantities was shown by the observations of Bolton and Fisch,* made in the course of an investigation into a deplorable accident in the city of St. Louis. A quantity of horse-serum containing diphtheria antitoxin was distributed before suitable tests were made, and the administration of this serum to diphtheritic patients was followed by fatal tetanus in a number of cases. The horse from which the serum was drawn is said at the time of bleeding to have shown no symptoms of tetanus, but some days later it developed tetanus and died. The amount of toxin in the blood of the horse was so great that 0.1 c.c. of the serum killed a guinea-pig in a few days, and nearly all the children who received as much as 10 c.c. of this serum were fatally affected.

The muscular cramps which characterize tetanus are due to a particular substance, the so-called *tetanospasmin*. This poison has a strong affinity for the nervous system of susceptible animals. The existence of a second toxin, *tetanolysin*, was first shown by Ehrlich. Tetanolysin, which is probably of less importance than tetanospasmin, exhibits special affinity for the red blood-corpuscles, with which it unites, producing laking. The two toxic bodies are quite distinct as regards combining relations and other properties, each giving rise to its specific antitoxin. It is not yet certain whether tetanolysin has any significance in connection with the ordinary symptom-complex.

Immunity.—Artificial immunity to tetanus, as determined by animal experiment, is associated with the production of an antibody

* Bolton and Fisch: Trans. Assoc. Amer. Phys., 1902, 17, p. 462.

which neutralizes the action of the tetanus toxin. The mode of action of tetanus antitoxin, so far as it is understood, is precisely like that of diphtheria antitoxin. The tetanus antitoxin circulates in the blood and is not taken up by either the central nervous system or the peripheral nerves. It can consequently bind only the toxin that finds its way into the circulation. Its curative value is much less than that of the diphtheria antitoxin; partly, perhaps, because the affinity of the tetanus toxin for nervous tissue is stronger than its affinity for the antitoxin; partly, perhaps, because of a relatively slight power of recuperation on the part of the central nervous system; and partly, also, because the toxin, when once incorporated in the axis-cylinders, is better protected from contact with the antitoxin than if it were in the circulation. According to Behring, there is no hope of success from subcutaneous injection of tetanus antitoxin after symptoms have existed for more than thirty hours.

To meet these difficulties special procedures have been employed, such as the infiltration with antitoxin of the large nerves of the affected part. In desperate cases intraspinal injections of antitoxin have been given with success. The neighborhood of the wound itself may also be infiltrated with antitoxin in order to neutralize toxin yet unbound. Repeated subcutaneous doses should always be administered.

The prophylactic value of tetanus antitoxin is much higher than its curative value, as might indeed be anticipated from the above facts. It is the opinion of some observers that tetanus can be almost altogether prevented by adopting the routine practice of administering antitoxin (about 10 c.c.) immediately in all cases of injury of a kind likely to provoke tetanus. In 1903 there were in the United States 406 deaths from tetanus in a total of 4449 Fourth of July injuries, while in 1907 there were only 62 in a total of 4413. The improvement is undoubtedly due in part to the increased prophylactic use of antitoxin, as well as to the better and more general cleansing and drainage of wounds. In veterinary practice tetanus antitoxin has been used prophylactically with great success.*

* Methods for the standardization of tetanus antitoxin are described in Bull. No. 43, Hyg. Lab., Pub. Health and Mar. Hosp. Service, Washington, D. C., 1908.

Bacillus Chauvei

An important and widespread disease affecting cattle, and known commonly as "blackleg," "quarter-evil," or "symptomatic anthrax" (Ger., *Rauschbrand;* Fr., *Charbon symptomatique*), is caused by an obligatory anaërobic bacillus, *B. chauvei* (*B. anthracis symptomatici*). So far as known, the disease is not communicable to man.

Morphology and Physiology.—The micro-organism of symptomatic anthrax is a large bacillus, which is variously shaped according to the particular stage of spore formation in which it is observed. The spore is larger than the diameter of the cell and lies within, in the middle of the rod or slightly toward one end, so that a spindle-shaped structure is produced which has been likened to a snowshoe or whetstone. These rods with immature spores are the so-called *clostridium* forms (Fig. 86). In cultures there appear successively long rods (12 to 24 μ), clostridium forms, and free spores; involution forms are frequent. The spores of B. chauvei are extraordinarily resistant, and when blackleg virus is once dried, it is very difficult to destroy it either by heat or antiseptics. Decolorization takes place by Gram's method.* Slight, sometimes active, motility is observed, and flagella can be demonstrated in young cultures.

Fig. 86.—Bacillus chauvei; clostridium forms from serum-gelatin culture; × 1200; Kitt prep. (Kolle and Wassermann).

Considerable variation occurs in cultures, perhaps due to slight differences in temperature, constitution of the culture-media, and origin of the different strains. Gas production in sugar media is vigorous, the agar in a tube culture being often shattered into fragments by the development of the bubbles. Gelatin is liquefied; the growth is in the depths of the tube, and is composed of rounded lobulated colonies with a dark center and a clear outer zone, suggest-

* Behavior toward the Gram stain is not always constant.

ing resemblance to a mass of amphibian eggs. Plate cultures are not characteristic. Milk is slowly acidified, coagulated, and proteolyzed. In broth, especially with the addition of fresh blood or blood-serum, luxuriant growth may take place, accompanied with profuse evolution of gas. According to Kitt,* one of the most careful students of this organism, the gas is without odor, the foul smell noted by some observers being due to contamination of the culture with anaërobic "cadaver bacteria." A soluble toxin is present in cultures in fluid media, especially in media containing blood or blood-serum. Intravenous injection of such a toxin is sufficient to kill a rabbit in a few minutes. This toxic substance loses its strength on exposure to air, but endures heating to 115° C.

Pathogenesis.—Symptomatic anthrax runs a rapid course, a case of natural infection usually terminating fatally in from one to two days. The local swellings are quite characteristic. These generally appear on the thigh, neck, or shoulder, and may attain a large size in a few hours. The affected muscles are of a dark, almost black, color, whence the name of blackleg. A considerable quantity of gas collects in the tissues, and the body is greatly swollen after death. Puncture of the swellings causes the emission of a red, serous, frothy, and malodorous fluid, which is infectious. Guinea-pigs are very susceptible to subcutaneous inoculation; rabbits, as a rule, prove immune. Feeding experiments on cattle and sheep are almost invariably negative. The disease appears ordinarily to be due to wound infection, the bacillus being widely distributed in soil; certain localities, however, may harbor particularly virulent strains. Transmission from case to case is rare.

Immunity.—Immunization is still in the empirical stage. Inoculations with unattenuated virus give uncertain and not very satisfactory results. Phagocytosis seems to have a share in preventing infection, as shown by the experiment of injecting sterile sand mixed with spores that by themselves are avirulent; under these circumstances some of the spores seem to be protected by the agglomerated sand grains, germinate and produce infection. A considerable degree of practical success has attended the use of dried virus for protective inoculation. In 1901–02 (July 1st to July 1st) 565,628 cattle were vaccinated in the United States; during the

* Kitt: Kolle and Wassermann, Handbuch, 2, p. 607.

previous season 14,817 deaths had occurred; in a similar period after vaccination the number of deaths was only 2902.

The vaccine distributed by the Bureau of Animal Industry of the United States Department of Agriculture is prepared as follows: The muscle tissue from a fresh blackleg tumor is pulverized in a mortar, extracted with a little water, and the fluid squeezed through a piece of cloth. This is then dried at 35°. The dry brown scale which results is suspended in water and injected in appropriate quantities as determined by tests and specified on each package distributed. The dried material retains a high degree of virulence for several years and can at any time be mixed with water (2 parts), heated for six hours at 95° to 99°, and inoculated (Norgaard's method).

An acute disease of sheep occurring in parts of northern Europe, and known as braxy (Bradsot), is associated with the presence of an anaërobic bacillus very similar to, if not identical with, B. chauvei. The clinical picture of braxy is said to be characteristic, the portion of the stomach known as the abomasum being chiefly affected. The braxy bacillus and B. chauvei are unlike in pathogenic power for various animal species, this being their chief demonstrable difference.

Bacillus Edematis

In 1877 Pasteur * discovered that inoculation of rabbits and guinea-pigs with fragments of putrid flesh produced a disease characterized locally by the accumulation of fluid (edema) in the tissues and also by degenerative changes in various organs. The affection could be communicated from individual to individual, and a rod-shaped, spore-bearing anaërobic organism, called by Pasteur the *Vibrion septique*, was found in the affected tissue. It was asserted later (Koch,† 1881) that the bacillus did not occur in any considerable number, in the blood, and that the disease could not therefore be regarded as a true septicemia. This is true, however, only of the larger animals; the small laboratory animals show a septicemic condition. The name *malignant edema* has been commonly applied to this affection since Koch's work (Ger., *Malignes Œdem;* Fr., *Oedème malin, Septicémie gangreneuse*).

Morphology and Physiology.—The size and shape of the bacillus of malignant edema and its mode of spore formation are

* Pasteur: Bull. Acad. de méd., 1877 and 1881.

† Koch: Mitt. a. d. kais. Gesund., 1881, 1, p. 53.

essentially similar to those of B. chauvei. Staining reactions are also the same. In fact, some observers have felt impelled to maintain the absolute identity of these two organisms. On morphologic grounds it is hardly possible to effect a definite separation, although B. edematis shows a greater tendency to grow in long filaments (Fig. 87). Culturally also the bacillus of malignant edema resembles the bacillus of symptomatic anthrax. Gelatin and blood-serum are liquefied, milk is curdled and the casein slowly digested, and gas is produced in media containing glucose. Cultures emit a very foul odor. The distribution of B. edematis is thought to be all but universal; it is reported as found with particular frequency in manured soil, in the cadavers of the larger animals, and in putrefying animal matter generally. Owing to the great similarity of the pathogenic anaërobes, it is possible that different organisms have been confounded and that the various members of this group are not as widely distributed as sometimes supposed.

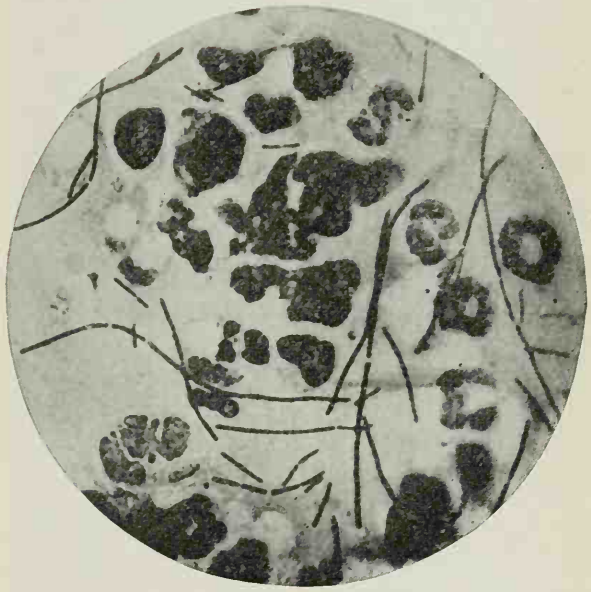


Fig. 87.—Bacillus of malignant edema. Tissue juice of guinea-pig after injection with a broth culture. Smear preparation, stained with fuchsin. × 1000 (Fränkel and Pfeiffer).

Pathogenesis.—Cases of alleged malignant edema in man have been reported a number of times, but have not always been authenticated by bacteriologic identification. This is true, for example, of the two cases of malignant edema described by Brieger and Ehrlich* as occurring after subcutaneous injection of musk, although these cases are ordinarily treated in the literature as the first recognized instance of this affection. It is now known that the clinical picture alone is not sufficient to distinguish cases of emphysematous

* Brieger and Ehrlich: Berl. klin. Wchnschr., 1882, 19, p. 661.

gangrene due to the bacillus of malignant edema from cases due to B. welchii.* In those cases where the bacillus of malignant edema has been isolated, the infection appears to start from fractured bones, deep wounds, etc. Intestinal infection, lung infection, and a case of pyosalpinx have also been traced to this organism.

Horses, and also sheep, cattle, and swine, suffer from occasional natural infection; epidemic prevalence is not common, although a preference is displayed for certain localities. Malignant edema is one of the "accidents of castration" in the horse; it has also been observed in cattle after parturition. Guinea-pigs, pigeons, rabbits, and hens are quite susceptible to inoculation; dogs and cats are more resistant. Experimental subcutaneous and intraperitoneal inoculation are most effective; intravenous injection is negative. Attempts to produce malignant edema by feeding animals with B. edematis have all been unsuccessful. Spontaneous infection in the domestic animals is largely dependent on serious mechanical damage to the tissues and on the presence of other microbes or chemical substances. In addition to these local predisposing factors an attack of malignant edema is favored by general influences, such as an attack of acute disease. It is possible that in some cases infection may be brought about by invasion of the tissues from the alimentary tract, in the contents of which B. edematis is usually present.

In the larger animals the bacillus is found in enormous quantities in the edematous fluid; it is generally absent from the internal organs during life, although spreading rapidly throughout the body after death. The guinea-pig, and still more markedly the mouse, show a septicemic condition, the bacilli being found in the blood of the mouse in great numbers immediately after death.

Bacillus Welchii (Bacillus Aërogenes Capsulatus)†

The organism most frequently found in cases of emphysematous gangrene in man is B. welchii, the so-called gas bacillus. This bacillus was discovered by Welch (1892) and also independently by E. Fränkel ‡ (1893, B. phlegmones emphysematosæ).

* Ghon, A., u. Sachs, M.: Centralbl. f. Bakt., 1904, 36, p. 200.

† Johns Hopkins Hospital Bull., 1900, 11, p. 185.

‡ Fränkel, E.: Centralbl. f. Bakt., 1893, 13, p. 13.

Morphology and Physiology.—Bacillus welchii is a plump, rather long bacillus (3 μ to 6 μ), occurring both in chains and singly; it is non-motile, anaërobic, and stains by Gram's method. Capsules are usually present in preparations made from the organs or body-fluids. Spores are formed by some races and are particularly likely to appear on blood-serum. Gelatin is liquefied slowly when at all. Gas is produced in dextrose, lactose and saccharose media, but not in mannit; a small amount of gas may be formed also from protein substances. Hydrogen predominates in the gas produced from sugar media, the ratio of hydrogen to carbon dioxid ranging from 2:1 to 3:1. Milk is coagulated with abundant gas-production and strongly acid reaction ("stormy fermentation"); the casein is not digested (Fig. 88). There is a typical odor of butyric acid in milk and glucose-agar cultures. Most varieties liberate hemoglobin when grown in broth to which blood has been added. A simple method of detecting the presence of B. welchii consists in adding a bit of sterile normal liver or other animal tissue to broth in the fermentation tube (T. Smith). When any material inoculated into such a tube contains the spores of B. welchii, gas usually develops abundantly in twenty-four hours at 37° C. MacNeal has found a slight modification of this method especially serviceable in recognizing the presence of the gas bacillus spores in feces.*

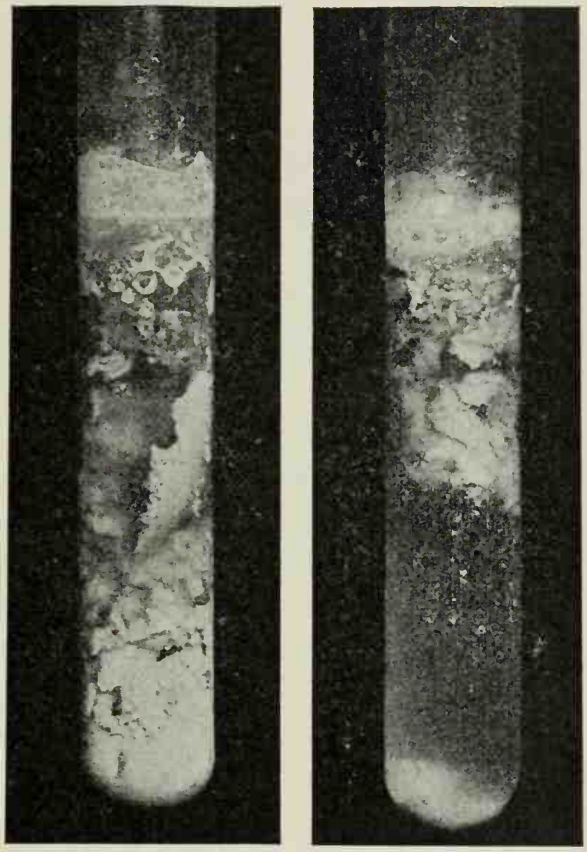


Fig. 88.—Typical reactions of Bacillus welchii in milk, forty-eight hours old. (N. MacL. Harris prep.)

* MacNeal, Latzer and Kerr: Jour. Infect. Dis., 1909, 6, p. 571.

Occurrence and Pathogenicity.—The gas bacillus is widely distributed; like many other anaërobic bacteria, it occurs commonly in the intestinal tract of the higher animals and in soil; it has been found also in dust, sewage, river-water, and milk. In man it is associated with a variety of pathologic conditions. "It is as a cause of that most dreaded of wound complications, emphysematous gangrene, that B. aërogenes capsulatus especially claims the interest of surgeons" (Welch). The bacillus has also been observed in closed abscesses in uterine infections, and in infections of the gastro-intestinal, genito-urinary, and biliary tracts. Several observers have isolated it from the blood during life. Study of the "foamy organs" sometimes observed at autopsy has shown that the presence of gas in the internal organs shortly after death is often attributable to an invasion by this organism (Fig. 89). The development of gas in the liver is a striking phenomenon in many of these cases.

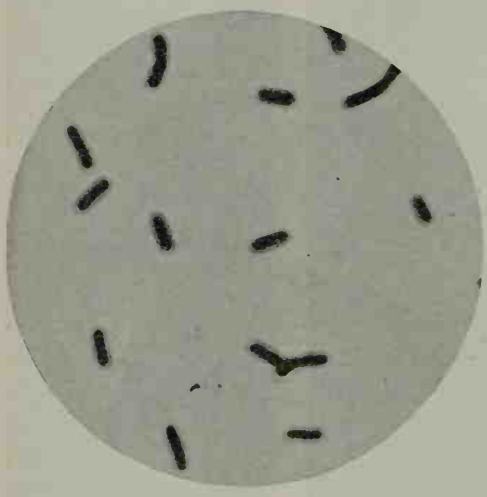


Fig. 89.—Bacillus welchii, showing capsule; × 1100.

Herter* has shown that in certain forms of disease the human intestinal tract contains an excessive number of bacilli belonging to this group. The characteristic type of "saccharo-butyric putrefaction" induced by B. welchii may perhaps give rise to products that bring about an anemic condition. Many instances of anemia in children and adults seem to be accompanied by a chronic infection of the intestinal tract by B. welchii, and as the general condition of the patient improves, there is a distinct reduction in the numbers of this organism found in the feces.

In the lower animals natural infection seems to be rare; local abscesses have, however, been observed by Harris† in dogs and rabbits following injury. Rabbits and mice are practically immune to simple inoculation. Dead rabbits have, however, been often

* Herter: Jour. of Biol. Chem., 1906, 2, p. 1.

† Welch: Bull. Johns Hopkins Hosp., 1900, 11, p. 204.

used as a culture-medium for the growth of this organism (Welch and Nuttall *). If the rabbit is killed a few minutes after intravenous injection of B. welchii and the body incubated at 37° C., gas is produced in a few hours throughout the body and a typical form of putrefaction is engendered. Gas may be liberated in the liver within four to six hours after inoculation. Guinea-pigs injected subcutaneously sometimes die with subcutaneous emphysema accompanied by extensive necrosis and tissue digestion, sometimes develop local abscesses, and sometimes are unaffected. This variation is ascribed to racial differences in virulence. The gas bacillus is also highly virulent for pigeons. The toxic substances produced by B. welchii are thought by McCampbell† to act not directly like true bacterial toxins, but indirectly through the generation of organic acids (*e. g.*, butyric acid), which are immediately injurious to the tissues.

The organism described by Klein‡ under the name of B. enteritidis sporogenes is very similar to, if not identical with, B. welchii. It is, however, declared to be motile and to produce spores rather readily. To its presence in milk Klein attributes certain epidemics of diarrhea, but there is no sufficient evidence for this view, especially since Glynn§ has shown that large numbers of the bacilli may be swallowed by a healthy man without producing any immediate ill effect. Some writers have proposed that the presence of B. welchii in water should be taken as evidence of sewage pollution, but the fact that the organism occurs abundantly in soil does not countenance the adoption of such a criterion. Great confusion has reigned in the field of identification and nomenclature. The following names probably refer to the same organism: B. welchii, B. aërogenes capsulatus, B. phlegmonis emphysematosæ, B. enteritidis sporogenes, and B. perfringens. A bacillus found by Achalme‖ and others in cases of acute rheumatism, and regarded by them as standing in causal relation to that affection, is almost certainly identical with B. welchii.

* Welch and Nuttall: Bull. Johns Hopkins Hosp., 1892, 3, p. 81.

† McCampbell: Jour. Infect. Dis., 1909, 6, p. 537.

‡ Klein: Centralbl. f. Bakt., 1895, 18, p. 737.

§ Glynn: Thompson-Yates Lab. Rep., 1901, 3, p. 131.

‖ Achalme: Ann. de l'Inst. Past., 1897, 11, p. 845.

Bacillus Botulinus

The consumption of certain animal foods in a raw condition is sometimes followed, after an interval of twenty-four to thirty-six hours or later, by a fairly characteristic set of symptoms frequently terminating in death. Raw sausage is the article of diet most commonly responsible for outbreaks of meat poisoning, and the name botulism (Lat., *botulus*, a sausage) is now applied to certain specific cases. Botulism is an intoxication caused by the products of an anaërobic bacillus discovered by van Ermengem in 1896.* A very similar if not identical affection, said to be common in Russia, has been traced to the use of raw salted fish. Mention has been made elsewhere of a different class of meat-poisoning cases due to B. enteritidis (Gärtner) (p. 262).

Morphology and Physiology.—B. botulinus is a large anaërobic bacillus with somewhat rounded ends (4 to 6 μ by 0.9 to 1.2 μ). It may occur singly or in pairs, or in short threads. In broth cultures kept at 37°, which is an unfavorable temperature for this organism, involution forms develop in the shape of very long twisted filaments. The organism is slightly motile, and possesses four to eight delicate peritrichal flagella; Gram's stain is positive. Oval spores are produced at one end of the cell (Fig. 90). The spores of B. botulinus are endowed with relatively slight resistance toward chemicals and heat, being destroyed by heating for one hour to 80° C. (van Ermengem).

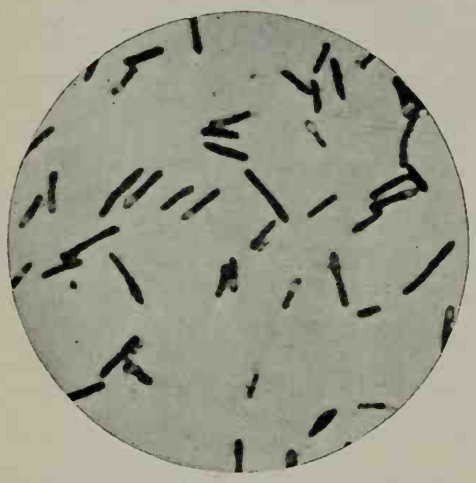


Fig. 90.—Bacillus botulinus, with spores. Pure culture on sugar-gelatin. Van Ermengem prep. (Kolle and Wassermann).

On glucose gelatin plates the young colonies are rather characteristic: they are spherical, translucent, of a yellowish-brown color, and are composed of coarse granules which show a steady streaming movement. A zone of liquid gelatin surrounds the colony. The

* van Ermengem: Ztschr. f. Hyg., 1897, 26, p. 1.

growths in glucose gelatin and agar tubes are not characteristic and resemble closely those of other anaërobes. Gas is produced from glucose, but not, according to van Ermengem, from lactose or saccharose. Milk is not curdled. Abundant growth takes place at ordinary temperatures (18° to 25° C.), while at 37° to 38.5° C. growth is scanty and is accompanied by the appearance of involution forms. Unlike the majority of pathogenic anaërobes, B. botulinus is apparently not widely distributed, and has been rarely found in the usual haunts of these organisms.

Pathogenesis.—Animal experiments have brought to light the highly remarkable fact that the pathologic changes associated with the presence of B. botulinus are not accompanied by any noteworthy multiplication of these germs in the living body. In a word, the deleterious effects produced by this organism are due, not to any poison that it forms within the animal, but to the substances generated by its growth outside the body. Van Ermengem has proposed the term pathogenic saprophyte for micro-organisms which, like B. botulinus, are lacking in virulence or power to grow in the animal body, but, like certain of the higher plants, such as poisonous mushrooms, the deadly nightshade, and the fungus of ergot (*Claviceps purpurea*), are dangerous by virtue of the poisonous compounds that are generated in their cells or in the substances in which they proliferate. Like the higher plants just mentioned, B. botulinus is not able to lead a parasitic existence in the bodies of warm-blooded animals. The behavior of this organism is doubtless correlated with its inability to grow well in broth at the body-temperature (37.5° C.). Rabbits, guinea-pigs, mice, apes and cats are very sensitive to the botulism poison, and die after small doses of fluid culture. A guinea-pig is killed by a drop or two of broth culture on a piece of bread. Still smaller quantities result fatally when given subcutaneously. Rabbits die in thirty-six to forty-eight hours after injection of 0.0003 to 0.001 c.c. The symptoms seem to originate largely from a toxic action on the medulla. Great muscular weakness and paralysis, profuse secretion from the mouth and nose, disorders of the eyes and other sense-organs, and derangement of the cardiac and respiratory centers, are among the usual accompaniments. At autopsy an intense congestion of the internal organs is observed, and microscopic examination reveals degener-

ative changes in the nerve-cells of the bulb and cord and in the salivary glands. Very small doses of the poison provoke local paralysis and lead to a cachectic condition which in some animals ends fatally after weeks or months.

In man the symptoms of botulism are very similar to those observed in the lower animals. It seems probable that in natural botulism, as in animal experiments, there is no true infection, but a preformed poison is responsible for the whole symptom-complex. The presence of B. botulinus or its toxin in meat is not necessarily associated with any of the ordinary signs of protein decomposition; it has been shown that meat of externally innocent character may give rise to botulism. At the same time, it must be recognized that the phenomenon is essentially connected with the processes of nitrogenous putrefaction, and that botulism is to be avoided by eschewing the use of raw, improperly conserved animal foods.

The Toxin.—The toxin produced by B. botulinus has aroused peculiar interest. It is not only of extraordinary potency when injected subcutaneously, 0.0001 c.c. of a fluid culture sufficing to kill a rabbit, but, in contrast to all other known bacterial toxins, it is highly poisonous when taken into the alimentary tract. So small a quantity as 0.01 c.c. of a glucose broth culture can produce death in twenty-four to thirty-six hours when administered to a monkey or rabbit through the mouth. The toxin is easily destroyed or rendered inert by light, heat, and various chemicals. Like the tetanus toxin, it is bound by an emulsion of the central nervous system, admixture of the toxin with such an emulsion being innocuous when injected into an animal. A botulism antitoxin has been produced by injection of small, gradually increasing doses of the toxin. The antitoxic serum thus prepared exerts in animal experiments an undoubted preventive and curative action.

Differentiation of the Anaërobes

There is comparatively little difficulty in distinguishing B. tetani from the other anaërobic organisms. Its morphology is quite characteristic. In stained preparations from a twenty-four- to forty-eight-hour culture grown at 37° C. the majority of the bacilli have the drumstick appearance caused by the large terminal spores. The feathery or tree-like growth in young glucose-gelatin stab

cultures is also characteristic. Unlike cultures of B. welchii and B. edematis, there is little or no gas formation in glucose-gelatin, slow liquefaction occurring after a few days.

Differentiation between B. welchii, B. edematis, B. chauvei, and B. botulinus is somewhat more difficult, for morphologically these organisms are very similar. One of the most ready tests for B. welchii is that devised by Welch and Nuttall,* and consists of injection of the bacilli into the ear vein of a rabbit, which is then killed after a few minutes by a blow on the head. The body is incubated, and in twenty-four hours the blood and organs are found to be filled with gas and bacilli. This demonstrates one of the most fundamental characteristics of B. welchii, the power of producing gas from protein material. The following points have also been given for distinguishing B. welchii from B. edematis: B. edematis is somewhat slimmer, has a greater tendency to grow into filaments, is less readily stained by Gram's method, produces spores more regularly, is motile, liquefies gelatin much more rapidly, generates less gas in lactose broth, first clots, then peptonizes, milk, with much less gas and with a putrid instead of a butyric acid odor. As to the effect produced by these two organisms in the animal body, in general, an absence of emphysema in the lesions is characteristic of B. edematis, while the presence of gas in the organs and tissues is a constant peculiarity of B. welchii.

Throughout bacteriologic literature there is uncertainty as to any distinction between the organisms causing malignant edema and blackleg. Morphologically, the bacilli found in these two diseases are practically indistinguishable, although it is said that B. edematis has a greater tendency to grow in long filaments, while B. chauvei more often shows the clostridium structure. B. chauvei is a very pleomorphic organism, two varieties having been described: (1) a sporeless, non-motile form without flagella, and (2) a spored motile form.† Varieties have also been found to differ as to their gas-production and their behavior in milk.‡ In fact, so different are the varieties that it is doubtful whether immunity produced

* Welch and Nuttall: Bull. Johns Hopkins Hosp., 1892, 3, p. 81.

† Grassberger, R., and Schattenfroh, A.: Archiv f. Hyg., 1903, 48, pp .1, 77.

‡ Smith, T., Brown, H. R., and Walker, E. L.: Jour. Med. Res., 14, 1905, p. 192.

by one type of organism would be effective against the other type Culturally B. edematis and B. chauvei are similar, although, according to Grassberger and Schattenfroh, the former grows best on slightly alkaline, the latter on slightly acid, media, and there is some difference in their biochemical products. It is in their relation to the animal body and in their distribution that they show the most constant differences. B. edematis is of widespread occurrence and may readily be isolated by inoculating a guinea-pig or rabbit with garden soil or dung. True symptomatic anthrax is rarely produced except by inoculation with material derived from the tissues of a diseased animal; furthermore, the virulent races are difficult to cultivate on artificial media without the presence in the culture-tube of some animal substance, such as a bit of sterile beef muscle. Rabbits, which are susceptible to B. edematis, are usually immune to B. chauvei, although intermediary bacteria are found which are pathogenic for these animals.

While morphologically B. botulinus is very similar to the groups of anaërobes just discussed, it is readily differentiated from them by its slight growth and non-sporulation at 37° C., the low resistance of its spores, the non-coagulation of milk cultures, and its non-production of disease in the animal body.

Bacillus Fusiformis

In an affection of the mucous membrane of the mouth and throat known variously as "ulceromembranous angina and stomatitis," "Vincent's angina," "pseudomembranous angina," etc., an anaërobic organism, B. fusiformis, has been described by a number of observers as being constantly present.* The symptoms and lesions are quite characteristic, and the affection seems rather prevalent, although, from its mild character, it generally passes unnoticed. The anaërobic bacillus is a long, slender organism with pointed ends, slightly swollen in the middle. Hence it is referred to as spindle-shaped or fusiform. It is non-motile according to most observers, and does not stain by Gram's method. In fluid media under anaërobic conditions growth is flocculent and whitish. Neither in fluid nor solid media, however, are the cultural features especially character-

* Weaver and Tunnicliff: Jour. Amer. Med. Assoc., 1906, 46, p. 482.

istic. A foul odor is usually present, but according to most observers there is no formation of gas-bubbles in glucose-agar.

In smear preparations made from the seat of the disease long spirilla are usually associated with the fusiform bacilli; in cultures all attempts to obtain the spirilla or spirochetes without admixture with bacilli have signally failed, hence the relation of these two forms has been the theme of much speculation. Some investigators have supposed that the bacilli and spirilla were distinct organisms, closely associated in some sort of symbiotic relation. Evidence exists, however, in favor of the view that these two forms are simply different phases in the life of one organism.*

A similar if not identical organism has been found in noma or gangrenous stomatitis † and in some other conditions.‡ Other anaërobic non-spore-forming bacteria have been occasionally observed associated with the production of gangrenous and fetid abscesses in various parts of the human body. As an example of this class may be cited B. mortiferus, described by Harris in connection with a fatal case of hepatic abscess in man.§

* Ruth Tunnicliff: Jour. Infect. Dis., 1906, 3, p. 148.

† For an excellent historical review of this rare condition see Weaver and Tunnicliff, Jour. Infect. Dis., 1907, 4, p. 8.

‡ See article by Babes on "Spindelförmiger Bazillen" in Kolle and Wassermann's Handbuch, Ergänzungsband 1, p. 271.

§ Harris: Jour. Exper. Med., 1901, 6, p. 519

CHAPTER XXII

THE TUBERCLE BACILLUS

No disease is so widespread or occasions so much distress and economic loss as tuberculosis. In 1900 in the United States 111,059 deaths, amounting to about one-ninth of the deaths from all known causes, were due to this disease. Baldwin estimates that tuberculosis costs the United States $150,000,000 to $200,000,000 yearly.*

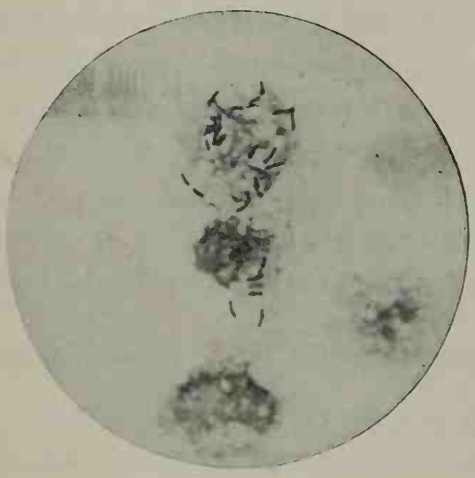


Fig. 91.—Bacillus tuberculosis, human, in pus from lung. Zettnow prep. (Kolle and Wassermann).

The fact that tuberculosis was a specific inoculable disease was shown by Villemin † as early as 1865, and the tubercle bacillus was probably seen in microscopic sections through tuberculous areas by Baumgarten ‡ in 1882. Robert Koch first established the etiology of tuberculosis on a solid basis.§ Koch succeeded: (1) In demonstrating by special staining methods that the tubercle bacillus was present in a great variety of affected organs and tissues; (2) in securing pure cultures of the bacillus in the face of great technical difficulties; (3) in performing successful inoculation experiments with the isolated cultures

Morphology.—In film preparations, made either from sputum or from cultures, the human tubercle bacillus ordinarily appears as a slender rod, often slightly curved, about 2 μ to 4 μ long and 0.3 μ

* Baldwin: Osler's "Modern Medicine," 1907, 3, p. 143.

† Villemin: Gaz. hebdom., 1865, 2 S., 5.

‡ Baumgarten: Centralbl. f. d. med. Wiss., 1882, 20, p. 257.

§ Koch: Mitt. a. d. kais. Gesund., 1884, 2, p. 1.

to 0.5μ broad (Fig. 91). The individual rods may occur singly, but often lie in small heaps. A capsular or enveloping substance is produced by tubercle bacilli. It is more abundant in human than in bovine cultures, and the amount becomes greater with the length of artificial cultivation on serum. In cultures a remarkable filamentous growth has been repeatedly observed, and in sputum also long branching, hypha-like filaments, sometimes with swollen ends, have been found. By some observers these clubbed and branching forms are regarded as abnormal or involution forms, possessing no significance in the normal life of the tubercle bacillus. Others, and perhaps the majority, consider that the branching filaments seen in cultures represent normal morphologic characters of the tubercle micro-organism. In the animal body likewise a stellate actinomyces-like (p. 414) growth is sometimes produced by the tubercle bacillus. Some bacteriologists, on the basis of these findings, class the tubercle bacillus either with the trichomycetes (Ch. XXVII) or with the true molds, while others place the tubercle bacillus and certain closely allied micro-organisms in a special group holding an intermediate position between the ordinary bacilli and the trichomycetes. Whatever be the final outcome of taxonomic discussion, the tubercle bacillus with its near allies must be regarded as standing rather apart from most other pathogenic bacilli, and possibly may eventually turn out to be "the parasitic growth-form of a higher mold."

The minute structure of the tubercle bacillus has likewise been the object of some discussion. Vacuoles often occur so abundantly as to give to the rod the appearance of a chain of cocci, and these unstaining spaces have been sometimes mistaken for spores, especially by the earlier students of the organism. More recently several observers have described small, deeply staining bodies within the cell, which in some of their morphologic and tinctorial characters resemble the spores formed by other bacteria. These spore-like bodies, however, display little or none of the heightened resistance to the action of heat and chemicals which is so characteristic a feature of other bacterial spores. The true nature of these structures is, therefore, still problematic. The tubercle bacillus is non-motile, and no flagella have been seen.

Staining.—The tubercle bacillus stains very imperfectly or not

at all with the ordinary aqueous anilin dyes, a fact that doubtless delayed the discovery of its presence in the tissues. If, however, the action of the dye is intensified by the aid of a mordant or by heat, the bacilli take on a deep coloration. Once stained, they retain the color tenaciously, even when treated with alcohol or strong mineral acids. This behavior is so characteristic that the tubercle bacilli, together with certain other related organisms, are frequently designated as "acid-proof bacilli." Some investigators, however, have described forms or phases of the tubercle bacillus which are not acid-proof.*

The examination of sputum for the tubercle bacillus may be facilitated by dissolving the mucus with dilute caustic potash (0.2 per cent.) and then collecting the sediment by centrifugalizing or allowing it to settle out by standing in a conical glass. If the sputum is examined without treatment, attention should be directed especially to the small yellowish particles that are frequently present, since tubercle bacilli are often found when these particles are crushed under a cover-slip.

Fig. 92.—Tubercle bacilli in phthisical sputum (Beck).

Staining may be accomplished by the use of Ziehl's carbol-fuchsin solution (p. 47), the cover-slip being flooded with stain, which is boiled for one-half minute. Follow this treatment by decolorization with acid alcohol (2 per cent. HCl in 80 per cent. alcohol), and contrast staining with methylene-blue (Fig. 93). The peculiar resistance of the tubercle bacillus to decolorization depends not upon any impermeability of the cell-envelop to acids, but upon the constitution of the cell body. The constituent of the cell especially responsible for their behavior is a peculiar wax-like substance. It has been shown that other kinds of bacteria can be made to acquire "acid-proof" qualities by being grown upon media containing fatty ingredients. Conversely, the waxy substance in tubercle

* See v. Behring, "Tuberculosis," 6, No. 9.

bacilli may be extracted with alcohol and ether, and the specific staining reaction simultaneously disappears. Chemically the substance to which acid resistance is due is believed by Bulloch and Macleod * to be an alcohol.

Cultivation.—It is not easy to cultivate the tubercle bacillus directly from tuberculous lesions. Growth fails to take place on ordinary nutrient agar or gelatin, and at first is slow and scanty even on the most favorable media. After cultivation has once succeeded,

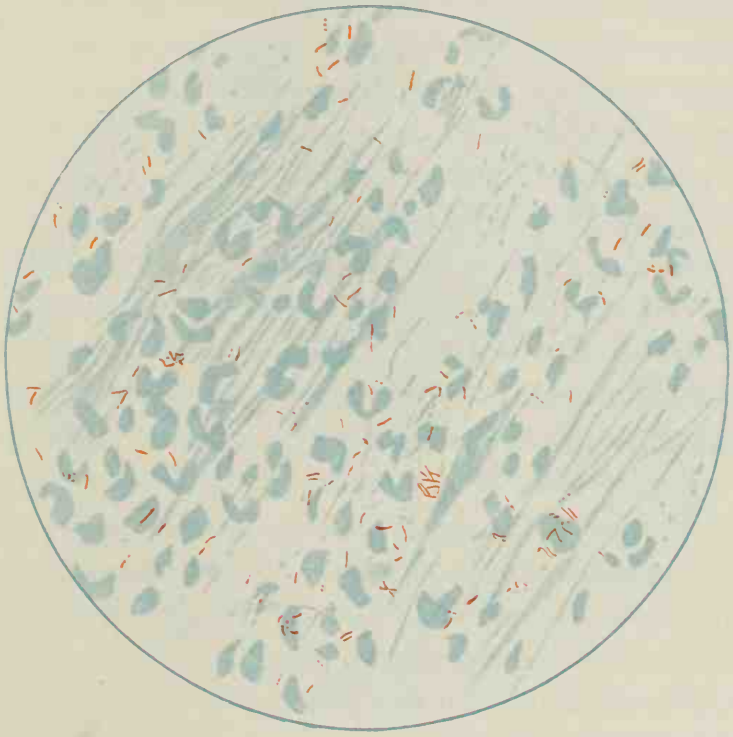


Fig. 93.—Bacillus tuberculosis in sputum, Ziehl-Gabbett; × 650 (Cornet and Meyer).

transplantation to another tube of the same medium will result in a more abundant growth, and in subcultures growth will take place upon media on which the bacillus fresh from the animal tissues fails to proliferate.

Koch first succeeded in cultivating the tubercle bacillus by the use of inspissated blood-serum, and this medium still remains one of the most satisfactory for isolation. Once cultures are obtained, they can be grown on a variety of substrata. Glycerin-agar (Nocard

* Bulloch and Macleod: Jour. Hyg., 1904, 4, p. 1.

and Roux *), prepared by adding 2 to 5 per cent. of glycerin to ordinary nutrient agar, has been widely used. Upon this medium subcultures can be made and a more luxuriant growth secured than by the continued use of serum; glycerin-agar, however, is not itself suitable for effecting a primary isolation. Glycerin broth is a favorable medium for well-established cultures and allows the development of a heavy growth. Care must be taken that the layer of broth is shallow and fosters a surface growth, since the tubercle bacillus requires an abundant supply of oxygen.

Many American workers have found especially useful a method employed by Theobald Smith † for cultivating the organism from the tissues which involves the use of dog-serum. The method as he gives it is as follows, viz.: "The dog was bled under chloroform and the blood drawn from a femoral artery, under aseptic conditions, through sterile tubes into sterile flasks. The serum was drawn from the clots with sterile pipets and either distributed at once into tubes or else stored with 0.25 to 0.3 per cent. chloroform added. Discontinued sterilization was rendered unnecessary. The temperature required to produce a sufficiently firm and yet not too hard and dry serum is, for the dog, 75° to 76° C.; for horse-serum it is from 4° to 5° lower. The serum was set in a thermostat into which a large dish of water was always placed to forestall any abstraction of moisture from the serum. About three hours suffice for the coagulation. When serum containing chloroform is to be coagulated, I am in the habit of placing the tubes for an hour or longer in a water-bath at 55° to 60° C., or under the receiver of an air-pump to drive off the antiseptic. This procedure dispenses with all sterilization except that going on during the coagulation of the serum. It prevents the gradual formation of membranes of salts, which, remaining on the surface during coagulation, form a film unsuited for bacteria. Tubes of coagulated serum should be kept in a cold closed space, where the opportunities for evaporation are slight. They should always be kept inclined. . . . . In inoculating these tubes, bits of tissue, which include tuberculous foci, especially the most recent, are torn from the organs and transferred to the serum. Very little crushing, if any, is desirable or necessary. I think many failures are due to the often futile attempts to break

* Nocard and Roux: Ann. de l'Inst. Past., 1888, 1, p. 19.

† Smith, Theobald: Jour. Exper. Med., 1898, 3, p. 451.

up firm tubercles. Nor should the bits of tissue be rubbed into the surface, as is sometimes recommended. After a stay of several weeks in the thermostat, I usually remove the tubes and stir about the bits of tissue. This frequently is the occasion for a prompt appearance of growth within a week, as it seems to put certain still microscopic colonies in or around the tissue into better condition for further development. The thermostat should be fairly constant, as urged by Koch in his classic monograph, but I look upon moisture as more important. If possible, a thermostat should be used which is opened only occasionally. Into this a large dish of water is placed, which keeps the space saturated. Ventilation should be restricted to a minimum. As a consequence, molds grow luxuriantly, and even the gummed labels must be replaced by stiff manila paper fastened to the tube with a rubber band. By keeping the tubes inclined, no undue amount of condensation water can collect in the bottom, and the upper portion of the serum remains moist. The only precaution to be applied to prevent infection with molds is to thoroughly flame the joint between tube and cap, as well as the plugged end, before opening the tube. When test-tubes are employed, it is well to dip the lower end of the plug into sterile molten paraffin and to cover the tube with a sterilized paper cap. The white bottle caps of the druggist are very serviceable."

Dorset's egg medium * affords a simple and easy method of isolating the tubercle bacillus from the tissues. Fresh, thoroughly cleansed eggs are broken into a sterile flask and the yolks and whites thoroughly mixed without frothing. The medium is placed in sterile tubes, about 10 c.c. in each, and hardened in the inspissator in a slanted position by heating on two successive days from four to five hours at 70° C.

Hesse's method has also proved very satisfactory for isolating the tubercle bacillus from sputum. After washing a bit of the sputum in physiologic salt solution (five to ten changes) it is drawn over the surface of a plate of Hesse's agar.† Upon incubating the

* Dorset: Amer. Med., 1902, 3, p. 555.

† "Nährstoff Heyden," "somatose," or "nutrose". 5 grams
NaCl. 5 "
Glycerin 30 "
Agar 10 "
Sol. Na_2CO_3 (cryst.) 28.6 per cent. 5 c.c.
Water 1000 "

plate for several days in a moist atmosphere, young colonies of the tubercle bacillus may be identified with a low power by their resemblance to minute wavy streaks.

When cultures are well established upon any medium, transfers may be made to a variety of other substances. Potato, carrot, macaroni, and other vegetable substrata have been successfully employed. The addition of glycerin to these substances facilitates development. Sander * obtained cultures direct from tuberculous lesions upon glycerinated potato.

Various synthetically prepared media have been used by Kühne † and others. Proskauer and Beck ‡ found growth to occur in a solution of the following simple constitution:

Ammonium carbonate	0.35 per cent.
Mono-potassium phosphate	0.15 " "
Magnesium sulfate	0.25 " "
Glycerin	1.5 " "
Water	97.8 " "

Biologic and Chemical Characteristics.—Upon the surface of blood-serum and glycerin-agar colonies of the tubercle bacillus appear in about ten days as minute, barely visible grains. They are dull and dry in appearance and irregular in outline. In cultures fresh from the tissues the colonies usually remain small and separate without confluence, but in subcultures, especially upon glycerin-agar, the growth is more luxuriant and the surface of the medium becomes covered with a wrinkled film (Fig. 94). The color of the growth is a lusterless white, often becoming faintly tinged with brown or yellow in old cultures. In glycerin broth growth may occur in separate patches on the surface, or may form a continuous, heavily wrinkled pellicle. Sometimes masses of bacilli sink to the

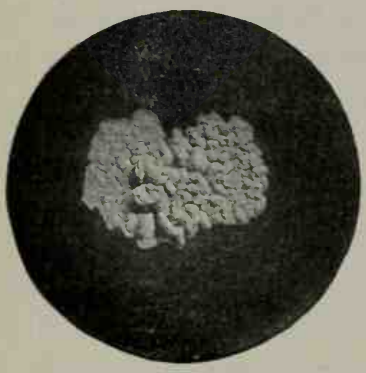


Fig. 94.—Bacillus tuberculosis, source human. Mature colony on glycerin agar. Actual size (Swithinbank and Newman).

* Sander: Arch. f. Hyg., 1893, 16, p. 238.

† Kühne: Ztschr. f. Biol., 1894, 30, p. 221.

‡ Proskauer and Beck: Ztschr. f. Hyg., 1894, 18, p. 128.

bottom of the fluid as a powdery sediment. A peculiar almond-like odor is often noticeable.

Whatever the medium employed, the temperature range within which growth occurs is a narrow one. The best development occurs between 37° and 38° C.; growth usually ceases above 42° and below 28°, although in glycerin-potato broth Sander * found growth to take place at a temperature as low as 22° or 23° C. Unlike most bacteria, the tubercle bacillus grows better on media of a slightly acid reaction; this is another feature in which it shows affinity with the molds or hyphomycetes.

The chemistry of the tubercle bacillus has received particular attention at the hands of investigators. The waxy substance in the cell, to which the tubercle bacillus owes its characteristic staining qualities, is believed to be, in large part, either an alcohol or a combination of certain fatty acids (chiefly palmitic acid) with the higher alcohols. Analysis of the ash of tubercle bacilli has given the following proportion of mineral elements:†

Oxid of sodium	13.62 per cent.
Oxid of potassium	6.35 "
Oxid of calcium	12.64 "
Magnesium	11.55 "
Carbon and silicic acid	0.57 "
Phosphoric acid	55.23 "

The large amounts of phosphoric acid, calcium, and magnesium are especially noteworthy.

Peculiar nucleoproteins have been extracted from the tubercle bacillus. Ruppel and Levene ‡ obtained three forms of nucleoprotein from bacilli grown on synthetic media. A nucleic acid of special constitution (tuberculinic acid) is formed by the breaking-down of the nucleoprotein. The nucleoproteins possess poisonous properties and are probably identical with the so-called "endotoxins" of the tubercle bacillus which have been extracted from the cell by various methods. Traces of these substances may pass into solution in a living culture, but there seems to be no secretion or excretion of true toxins during active growth.

* Sander: Arch. f. Hyg., 1893, 16, p. 238.

† De Schweinitz and Dorset: Centralbl. f. Bakt., 1898, 23, p. 993.

‡ Ruppel and Levene: Ztschr. f. physiol. Chem., 1898, 26, p. 218; Jour. Med. Res., 1901, p. 135.

Powers of Resistance.—Although multiplication of the tubercle bacillus can take place, as a rule, only within a narrow range of conditions, the vitality of the bacillus under adverse circumstances is considerably greater than that of most pathogenic bacteria. In putrefying sputum it may occasionally remain viable for weeks or even months. Musehold * has found it in the soil of sewage fields and in sewers connected with sanitaria for consumptives.

Considerable resistance to desiccation is shown. The bacilli in masses of dried sputum kept in a cool dark place may retain their virulence for as long as six to eight months, but not for much longer periods. Sputum that is completely dried, so that particles are capable of floating as dust in the air, may be infective for eight to ten days, rarely longer.

Toward dry heat the bacilli are highly resistant, being able, if in dried sputum, to withstand a temperature of 100° C. for an hour. When they are heated while suspended in a fluid, such as water, broth, or milk, Theobald Smith has shown that death occurs in fifteen to twenty minutes at 60° C. If, however, milk is heated at this temperature in an open vessel, the pellicle that forms in contact with the air may protect the bacilli against a temperature of 60° for as long as an hour. Pasteurization, to be effective, therefore, must be carried out in a closed vessel at 60° C. for twenty minutes. Boiling for five minutes completely destroys the vitality of the bacilli. As in the case with most bacteria, extreme cold is not germicidal.

Carbolic acid (5 per cent. solution) added to sputum requires a long time (twenty-four hours) to kill the bacilli because of its slow penetration. Lysol, which has a solvent action on mucus as well as strong germicidal power, is to be preferred. Gastric juice, because of its acidity, impedes development, but does not kill all bacilli introduced into the stomach; an experiment has been recorded in which the gastric juice of a dog did not destroy the vitality of tubercle bacilli in eight hours.

Exposure to direct sunlight readily effects the destruction of tubercle bacilli, especially in the presence of abundant oxygen supply. The conditions of exposure determine the time necessary to produce death, but, broadly speaking, bacilli from cultures are killed in a few minutes to two hours, while bacilli in sputum require twenty to thirty hours, or even longer.

* Musehold: Arb. a. d. kais. Gesamt., 1900, 17, p. 56.

Tuberculous Infection in Man.—Practically every organ and tissue of the human body may be invaded by the tubercle bacillus. As is well known, the lungs constitute the seat of the most common lesions, but the intestines and mesenteric glands, the larynx, the skin, the lymph-glands of the head and neck, the portal glands and liver, the bones and joints, and the urogenital system are frequently attacked. In ordinary cases of tuberculosis there is no conclusive proof of the frequent and continued presence of tubercle bacilli in the blood. Statements of positive findings seem to be due to the presence of acid-proof bacilli in the distilled water used for making the microscopic examination.* Lesions caused by the tubercle bacillus, in whatever part of the body they occur, usually possess a definite although not absolutely characteristic appearance and histologic structure. Small nodules or tubercles, plainly visible to the naked eye, are so uniformly observed in all advanced infections with the tubercle bacillus that their presence has given the name to the disease. The young tubercle, according to the opinion of most investigators, originates from the fixed cells surrounding the invading bacilli. By the proliferation of the fixed cells elongated or "epithelioid" cells are developed in more or less definite concentric layers and come to form the substance of the tubercle. So-called giant-cells soon appear in the developing tubercle in the majority of cases. The giant-cells are huge multinuclear masses of protoplasm, of oval or irregular shape, and have been held to be especially distinctive of true tubercle formation, although it is doubtful if this criterion can be maintained. As a rule, a giant-cell appears to arise from the enlargement of a single epithelioid cell, although it is maintained by Metchnikoff and some others that the giant-cell is produced by fusion of a number of epithelioid cells. While the formation of epithelioid and giant-cells is going on, leukocytes (at first lymphocytes, later polymorphonuclear leukocytes also) which have wandered out of the blood-vessels cluster around the periphery of the tubercle. Degeneration of the tubercle eventually sets in, the central portion becomes necrotic, and this is followed by caseation and then by softening of the caseous mass. Finally, in many cases a deposit of calcium salts takes place in the tubercle, converting it into a hard, dry,

* Brem: Jour. Amer. Med. Assoc., Sept. 18, 1909.

friable body which may become encapsulated and completely walled off from the surrounding tissue.

The early stages of tubercle formation, which are characterized by cell proliferation and leukocytic infiltration, are probably to be referred to a chemical or mechanical stimulus caused by the presence of the bacilli; the later changes, leading to cell necrosis and caseation, are reasonably attributed to the toxic action of the bacterial products. The hardening, drying and shrinking of a tubercle probably betoken a healing process. Coalescence or conglomeration of tubercles commonly takes place, the confluent masses sometimes reaching a diameter of 4 or 5 centimeters. In severe cases there occurs a general diffusion of small tubercles of the size of millet-seeds (acute miliary tuberculosis). This form of the disease seems to depend upon the simultaneous or nearly simultaneous discharge of large numbers of bacilli into the blood-stream, an event that may be brought about by erosion of the vessel wall by a tuberculous process approaching from without, or in other ways.

The work of Prudden and Hodenpyl,* Straus and Gamaléia,† and others has established the important fact that the injection into the circulation of dead tubercle bacilli in considerable numbers can lead to typical tubercle formation. The substance present in the dead bacteria that produces this reaction is not destroyed by high temperatures, as shown by the positive results obtained after exposure of the bacilli to 115° C. for ten minutes. In these experiments giant-cell formation takes place in apparently the same way as under the stimulus of living bacilli, but caseation develops, when at all, only to a slight degree, and is never extensive.

Tuberculous Infection in the Lower Animals.—(*a*) *Mammalian Tuberculosis.*—Among the larger domestic animals, cattle and swine are most commonly found affected. The horse is very rarely attacked, and sheep also appear to be relatively exempt. Slaughter-house statistics in Europe show that about 15 to 30 per cent. of cattle and about 2 to 3 per cent. of swine are tuberculous. In the United States, as far as the figures are available, the proportion of tuberculous animals slaughtered in abattoirs is not nearly so great as in Europe. According to the reports of the United States Bureau of Animal Industry, 28,000,000 cattle were

* Prudden and Hodenpyl: N. Y. Med. Jour., 1891, 53, pp. 637, 697.

† Straus and Gamaléia: Arch. méd. expér., 1891, 3, p. 705.

subjected to post-mortem examination during the years 1900–1905, and 0.134 per cent. were found to be affected The large proportion of range cattle that have led an open-air life is probably responsible for this favorable showing. In countries where the delicate tuberculin test has been systematically applied a larger number of animals is found to react than is indicated by the results of slaughter-house inspection.

Animals in menageries and zoölogical gardens frequently die of tuberculosis. The smaller laboratory animals, as a rule, are susceptible to artificial inoculation, although not contracting the disease under natural conditions. In experimental work the guinea-pig is chiefly used.

The anatomic and clinical features of bovine tuberculosis are in the main similar to those of human tuberculosis, but show also some differences, such as the earlier calcification of the tubercles and the extraordinarily slow progress of the disease. When the pleuræ are affected, nodules appear in greater or less abundance on the visceral or parietal surfaces, a condition that constitutes the so-called pearl-disease (Ger., *Perlsucht*) of cattle.

The important question whether the tubercle bacilli found in bovine, human, and other varieties of mammalian tuberculosis are identical, whether, in other words, a single type of micro-organism is responsible for all the various forms of mammalian tuberculosis, is in a certain sense not ripe for solution. The features that should characterize a "bacterial race or species" have not yet been established, and until some consensus of opinion on this point has been reached, discussion of specific identity is futile. As often presented, the issue is simply one of potential transformation. The subject of types of tubercle bacilli has received particular attention in connection with the relation between bovine and human tuberculosis. There are certain slight but constant differences between the bacilli isolated from human sputum and tissue lesions and those of bovine origin. The bacilli obtained from cattle are shorter, straighter, and thicker than those obtained from man; they are cultivated less readily, as a rule, on artificial media, and they are uniformly much more virulent for rabbits (Theobald Smith). In glycerin broth 2 per cent. acid to phenolphthalein, and containing at least 3 per cent. of glycerin, the reaction produced by human cultures remains permanently acid to phenolphthalein, while with

bovine cultures the originally acid reaction diminishes, and when the conditions for the multiplication of the bacilli are favorable, a feebly alkaline reaction is eventually reached (Theobald Smith*). There is no doubt, from the experiments of Smith, Koch, and others, that cattle can be less readily infected with human tubercle bacilli than with cultures from bovine sources. In itself this does not prove a specific distinction, any more than the limited number of successful inoculation experiments that have been reported by other investigators prove a specific identity. The possibility must be kept in mind that bovine tubercle bacilli, after a sojourn in the body of man, may become altered not only in minor morphologic and cultural characters, but in virulence for cattle. On the whole, the evidence at hand indicates that the tubercle organisms found in the bodies of different species of mammals are so closely related that it is permissible to speak of them together as "the bacillus of mammalian tuberculosis," but it is also true that the question whether the different morphologic and physiologic varieties are biologically permanent "races" or are mutually convertible is an open one. It is still uncertain how far tubercle bacilli of bovine type may be modified by residence in the human body. There are some observations which show a pronounced stability of type. Hess† has recorded 2 cases in which bovine tubercle bacilli lived in human cutaneous tissues for six to seven years without acquiring characteristics of the human type.

(*b*) *Avian Tuberculosis.*—Tuberculosis is one of the commonest diseases of the barnyard. Fowls particularly, and also pheasants, turkeys and pigeons, suffer from this disease; ducks and geese are exempt.

The bacillus of chicken tuberculosis is similar morphologically to the bacillus of bovine tuberculosis, and also resembles the latter organism in its staining reactions. Culturally certain differences are usually manifest, such as a more luxuriant development, together with a softer, less crumbly consistency, and an ability to grow at higher temperatures (43° to 45° C.). The pathogenicity of the organism is quite different from that of bovine tuberculosis, the guinea-pig showing much greater resistance and the rabbit less

*Smith, Theobald: Trans. Assoc. Amer. Physicians, 1903, 18, p. 108; Jour. Med. Res., 1905, pp. 253, 405.

†Hess: Jour. Amer. Med. Assoc., 1909, 53, p. 916.

than to the mammalian type. Hens and pigeons, which succumb readily upon inoculation with the bacillus of avian origin, are infected with difficulty, if at all, with the bovine bacillus.

Among the more important attempts to transform the mammalian into the avian tubercle bacillus may be mentioned that of Nocard,* who introduced the former organism in a collodion sac into the peritoneum of a fowl and observed a general approximation toward the avian type. M. Koch and L. Rabinowitsch, in the course of an extensive study of the bacilli found in the tuberculous lesions of birds, were unable to demonstrate any constant difference from the bacilli of mammalian tuberculosis.†

(*c*) *Tuberculosis of Cold-blooded Animals.*—A disease affecting carp has been found to be apparently caused by a micro-organism somewhat resembling the tubercle bacillus in its reaction to stains and in other qualities. This microbe is pathogenic for frogs. The assertion has been made by some investigators that when the mammalian tubercle bacillus is introduced into the body of frogs it gradually acquires the characteristics of the piscine bacillus. Most investigators have failed to confirm such a transformation. Bacteria similar to the tubercle bacillus have also been found in snakes, lizards, and other cold-blooded animals; they seem to resemble more nearly the acid-proof "dung" bacilli than the bacilli of the mammalian type.

Channels of Infection.—(*a*) *Respiratory Tract.*—It is known that tubercle bacilli are discharged commonly from the bodies of consumptives (1) in the sputum and (2) in minute droplets of moisture or mucus which are projected into the air by the act of sneezing, coughing, or talking. There is no reason to believe that the tubercle bacillus flourishes saprophytically outside of the body, and this fact, together with the existence of a large number of consumptive persons in every community, points to a more or less frequent and direct communication of the disease through the air. Many facts, epidemiologic and other, support this view.

The sputum of consumptives often contains an enormous number of germs. It has been estimated, from carefully obtained data,‡

* Nocard: Ann. de l'Inst. Past., 1898, 12, p. 561.

† Koch and Rabinowitsch: Virchow's Archiv, 1907, Supplement to Vol 190, p. 246.

‡ Johns Hopkins Hosp. Bull., 1891, 2, p. 67.

that a patient suffering from phthisis may expectorate from 500,000,000 to 3,000,000,000 tubercle bacilli in twenty-four hours. Although not all of these germs possess vitality at the start, and under ordinary conditions in the open many of the discharged bacilli quickly perish from the influence of desiccation and sunlight, some may retain their vitality for several months. Bacilli are not detached from moist surfaces even by a strong current of air, so that only those bacilli that survive long enough to appear in the dust resulting from the dried sputum have much significance in infection. From the foregoing facts it is evident that the danger from inhalation of sputum bacilli is much greater in rooms, offices, public conveyances, and workshops frequented by consumptives than in the open country or even in dust-laden city streets. Careless expectoration upon the floor or into a handkerchief is the main cause of peril from this source. It can be readily seen how a handkerchief upon which sputum has been allowed to dry in the pocket, away from the influences of light and air, may be the means of spreading infection when again flourished in the air in a room, shop, street-car, or anywhere in the neighborhood of other persons. The existence of "infected houses"—a term used by several observers to characterize dwellings in which a succession of cases have appeared in the families of different tenants—witnesses to the evils of careless expectoration in closed apartments.

It is a common observation that in the act of speaking, coughing, or sneezing minute drops of fluid are violently projected from the mouth. The researches of Flügge and his pupils indicate that a certain proportion of the droplets expelled by consumptives contain living and virulent tubercle bacilli. These infectious droplets may float in the air for some time (thirty minutes?), and render the immediate neighborhood of the coughing patient more or less of a menace. The droplets are found only rather rarely at a greater distance than 3 or 4 feet from the patient, and the danger of infection from this source is, therefore, circumscribed both in space and time. The relative importance of droplets and dust in producing infection is a matter of dispute. Practically both possibilities must be taken into consideration.

(*b*) *Infection through the Alimentary Tract.*—This pathway of infection has come into greater prominence through the investigations of recent years. Tubercle bacilli may conceivably find their way

into the mouth in many ways. There is evidently some danger when infants or children soil their fingers with infected dirt by creeping or playing on the floor, or when the common drinking-cup or the imperfectly cleansed spoon and fork are used. In fact, transference to the hands and food may take place from a variety of contaminated objects. Food may sometimes be infected through the agency of insects. It has been shown that flies can ingest tuberculous sputum and subsequently excrete virulent bacilli during a number of days.* The possibility of repeated self-infection of a consumptive from swallowing his own sputum may be mentioned as a peril to be avoided.

The milk and butter of tuberculous cattle are the articles of diet chiefly suspected of causing tuberculous infection by way of the alimentary tract. It has long been known, from the results of feeding and inoculation experiments, that the milk of tuberculous cattle is sometimes infectious. It has been shown more recently that not only milk drawn from a diseased udder is liable to contain tubercle bacilli, but also milk from an udder showing no macroscopic or microscopic lesion. Several observers have found that the milk of cattle which react to the tuberculin test, but present no other sign of the disease, *even on autopsy*, is infective. In many, perhaps all, of these cases the soiling of the udder with feces is responsible for the presence of the tubercle bacillus in the milk (Ostertag). Schroeder and Cotton† have, in fact, concluded that feces are the most dangerous factor in the dissemination of tubercle bacilli by cattle affected with tuberculosis. The available evidence seems to indicate that tubercle bacilli are not eliminated in the milk from tuberculous cows unless the udder or surrounding parts are themselves diseased, but practically the danger of infection of the milk after it has been shed must be considered, especially the contamination of the milk with feces containing tubercle bacilli.

Butter made from the cream of tuberculous animals may likewise contain living bacilli for as long as one hundred and fifty-three days.‡ Gasperini§ added tubercle bacilli to butter and found the butter virulent after one hundred and twenty days.

* Lord: Boston Med. and Surg. Jour., 1904, 151, p. 651.

† Schroeder and Cotton: Bull. 99, Bureau of Animal Industry, U. S. Dept. Agri., 1907.

‡ Mohler, Washburn, and Rogers: Bull. 41, Hyg. Lab., Washington, 1908.

§ Gasperini: Baumg. Jahresb., 1890, 6, p. 271.

Meat from tuberculous cattle, although muscle tissue itself does not ordinarily contain tuberculous lesions, may become contaminated during removal from the carcass by being smeared with material from an infected gland coming in contact with the knife or cloth used by the butcher. Feeding experiments upon animals show that raw meat is a much less infective material than raw milk. So far as human infection is concerned, the general use of thoroughly cooked meat minimizes the danger from this source. Although various food-substances derived from tuberculous animals prove infectious in animal experiments, it does not necessarily follow that they are a frequent or an ordinary source of infection in man. Considerable difference of opinion exists concerning the relation between bovine and human tuberculosis, and the importance of this question renders desirable its discussion in a separate section (p. 353).

Much interest in recent years has centered about the manner, frequency, and results of gastro-intestinal tract infection. Many experiments have demonstrated that bacilli can pass through or between intact epithelium cells and thence into the mesenteric nodes or thoracic duct. According to most observers, passage can take place without leaving any trace in the intestinal wall, but some hold that some tissue change, however slight, is always produced. It appears to be true that in experimental work enormous numbers of bacilli are necessary to produce infection. The final localization or site of predilection of the bacilli entering the lymphatic system from the intestines is a matter of great importance. Von Behring maintains that the vast majority of all cases of lung tuberculosis are of intestinal origin, and there is no doubt that pulmonary tuberculosis can originate from swallowing tubercle bacilli. In late years the opinion has gained ground that the bacillus not uncommonly makes its way to the lungs by the intestinal route rather than by direct inhalation. The relative frequency of alimentary as compared with respiratory infection can hardly be determined by the facts so far gathered.*

(*c*) *Inoculation.*—Infection may take place by direct cutaneous or subcutaneous inoculation of tubercle bacilli, either by accidental infection at post-mortem examinations, giving rise to the so-called

* For review of literature on this subject, see Reitz, Centralbl. f. Bakt., 1906, II, 16, p. 193.

"pathologists' warts," or in other ways. Considerable resistance is shown by man to infection by this route, and the results of skin infection are rarely serious. Ravenel,* however, has recorded cases in which accidental inoculation of man with bacilli of bovine origin has resulted in serious lesions.

The Relation between Bovine and Human Tuberculosis.— Widely divergent views are held respecting the danger to man of infection from bovine sources. On the one side there are those who, like v. Behring,† maintain that the common forms of tuberculosis usually originate in infancy through intestinal infection with milk, and that the bacilli remain latent in the tissues for long periods; on the other, there are eminent authorities (Koch) who have declared that the susceptibility of man to bovine tuberculosis is slight, and that infection with the milk, butter, or flesh of tuberculous animals is a very rare occurrence. The question is complicated and its experimental solution presents many technical difficulties.

The difference between tubercle bacilli from bovine and human sources has already been mentioned. It was first clearly established by the work of Theobald Smith that the bovine tubercle bacillus was a distinct variety or race of the mammalian tubercle bacillus, and as such possessed certain definite and rather constant characters. Some modifications may occur in passing from host to host, but Smith believes that "the modification of bovine bacilli in the same human body beyond recognition as such by the bacteriologist, if it ever occurs, necessarily presupposes a prolonged sojourn, probably of years at the shortest."‡ Granting a fair degree of constancy, it follows that tubercle bacilli recovered from the human body may be identified with more or less certainty as of bovine or human origin. A number of observers have encountered bacilli of the bovine type in the human subject, and it is therefore plain that, so far as this line of evidence goes, infection with bovine bacilli can and does take place. At the same time, it must be noted that the fully studied and established cases of this sort are few in number, and that there is still inadequate information

* Ravenel: Proc. Path. Soc., Phila., 1900, 3, p. 259; 1902, 5, p. 87.

† Von Behring: Deut. med. Wchnschr., 1903, 29, p. 689.

‡ Smith, Theobald: Med. News, 1902, 80, p. 343.

respecting the relative frequency with which bacilli of the bovine type are found in human tuberculosis.

Inoculation experiments have shown that cattle may be infected with human tubercle bacilli and sputum, contrary to the view at one time enunciated by Koch.* Evidence that the converse also may occur is not lacking. Accidental wound inoculation of veterinarians with bovine bacilli has resulted in typical localized subcutaneous tuberculosis, which in some cases has become generalized and led to a fatal termination (Ravenel, *et al.*). These facts, however, important though they are, do not prove that the food-products from tuberculous cattle constitute a common and ordinary means of infection.

For various reasons it is peculiarly difficult to secure data as to the frequency of intestinal infection. Ingested bacilli can sometimes pass through the intestinal wall without leaving visible trace of their passage, and may finally lodge and proliferate at some point far removed from their portal of entry. Tubercle bacilli have been found in the thoracic duct shortly after they have been fed to an animal in large numbers.† Pulmonary tuberculosis can therefore undoubtedly sometimes arise secondarily after invasion of the body of the intestine. Harbitz ‡ has demonstrated the frequent occurrence of tubercle bacilli in the lymph-nodes of children, and his observations have added emphasis to the frequency of primary infection through the digestive tract. In such cases, however, it is impossible to determine from anatomic data whether the bacilli are contained in the food taken and are of bovine origin, or whether they are bacilli of human origin that have entered the mouth and lymph-nodes. Hence the peculiar importance of the differential characters of bovine and human bacilli already referred to. A number of instances are on record where all the available evidence, bacteriologic and epidemiologic, indicated that the infected milk of cows was responsible for the causation of tuberculosis in children. Infection from this source seems especially liable to occur when the intestine is flooded with enormous numbers of tubercle bacilli, as may happen in the use of milk from cows suffering

* Koch: Address at British Congress on Tuberculosis, 1901.

† Ravenel: "Medicine," Detroit, 1902, 8, pp. 529, 617.

‡ Harbitz: Jour. Infect. Dis., 1905, 2, p. 143.

from bad cases of udder tuberculosis. Recognizing that the milk from tuberculous cattle can serve as the vehicle of infection, it is as yet impossible to determine the precise share such infection has in producing the total amount of tuberculosis in any community. Data, however, are beginning to be collected. Park* has estimated that about 1.5 per cent. of all cases of fatal tuberculosis in New York City are due to bovine infection. In this connection it is significant to note that in Japan,† where cows' milk plays no rôle at all in the feeding of children, the totality of tuberculosis is at about the same level as in countries where bovine food-products are common articles of diet. Furthermore, primary intestinal tuberculosis is relatively common in Japanese adults and children, although bovine products can have no share in its production. As regards the possibility of transfer from man to animals under natural conditions, the statement is made that there are large districts in Japan where, in spite of the existence of human tuberculosis, the cattle remain absolutely free from the disease. On the whole, therefore, it seems to be true that while the danger of occasional and serious infection of man from bovine sources is such as not to justify the relaxation of protective and preventive measures, any common and, far less, any universal (v. Behring) infection of adults is at present unproved.

Predisposing Factors.—Few diseases are so completely under the sway of predisposing influences as tuberculosis. Modern city life, especially, affords many opportunities for infection, and a large majority of human beings undoubtedly swallow or inhale tubercle bacilli at some time during their existence. It is probable that nearly all adults living in cities become infected to a greater or less degree. Nägeli,‡ in a comprehensive study of five hundred autopsies upon the bodies of adults dying from all causes, in which the tissues were examined with particular care, found tuberculous lesions in 97 per cent. Infection in early life is probably more common than has been supposed; Harbitz § demonstrated latent tubercle bacilli in the lymph-nodes of eighteen children under eleven years old, none of whom showed any evidence of tuberculous lesions.

* Park: Jour. Amer. Med. Assoc., 1909, 53, p. 1808.

† Kitasato: Amer. Med., 1905, 9, p. 13.

‡ Nägeli: Virchow's Arch., 1900, 160, p. 426.

§ Harbitz: Jour. Infect. Dis., 1905, 2, p. 143.

Practically but a small proportion of persons escape infection. It is only, therefore, when there is a concurrence of favoring factors that tubercle bacilli are able to gain a foothold and proliferate to such an extent as to overpower the natural resistance of the organism. Among these predisposing conditions may be mentioned especially the influence of dampness, of sedentary life, of insufficient or unsuitable food, and generally of the features of an "indoor" environment. Alcoholism is another very important predisposing factor, although it is often difficult to separate its effects from those of its bed-fellow, poverty. The baneful results of wasting diseases like diabetes, typhoid fever, and whooping-cough are well known to all physicians. The influence of occupation is often marked, any trade involving the breathing of dust claiming a disproportionate number of victims from consumption. Thus English statistics show that, taking the death-rate from tuberculosis and other affections of the respiratory system among agriculturists as 100, the rate among potters and workers with earthenware is 453, that of cutlers 407, of plumbers 373, of glassmakers 335, etc.* Excessive temperature and moisture have a similar influence, as shown in the disproportionate number of deaths among laundry workers and the operatives in wet spinning-rooms. The effect of mode of life not only upon the inception, but upon the progress, of the disease is well known. It is a commonplace that pulmonary tuberculosis may often be definitely arrested by a change in the manner of living. Wild animals in a state of nature are not naturally liable to the disease, but when kept in confinement in zoölogical gardens often quickly succumb. From a biologic viewpoint tuberculosis is primarily and chiefly a disease of men living in houses and of cattle kept in stables.

It is reasonable to attribute part of the marked decline in the death-rate from consumption which has occurred in nearly all civilized countries † during the last few decades to a widely diffused amelioration in the conditions of life. Better food, better ventilation, shorter hours of work, and a more general education respecting the possibilities of infection are all potent agencies in restricting

* Newsholme: Vital Statistics, London, 1898, p. 183.

† In London the tuberculosis death-rate fell from 3.12 in 1884 to 2.34 in 1901; in Berlin from 3.6 in 1884 to 2.39 in 1902; in Vienna from 7.2 in 1884 to 4.76 in 1900; in New York from 4.45 in 1884 to 2.79 in 1903.

infection. Newsholme * believes that the establishment of special hospitals and retreats for advanced cases has been the main factor in producing the decline in tuberculosis which has taken place in recent years in most civilized communities.

From the foregoing considerations the advantages of compulsory notification of all cases of tuberculosis seem to be manifest. The proper disinfection of the dwelling-places, the protection of the patient and his friends, and the education of the community at large can be accomplished only by this means. The most important sources of infection and the most mischievous predisposing influences can thus be brought under administrative control.

Heredity.—That heredity exercises a marked influence upon tuberculosis has been long an article of popular belief. When examined, however, this belief is seen to rest upon a hardly adequate foundation. Association of parents and children in the ordinary intimate home life presents so numerous and so favorable opportunities for communication of the disease that it is natural enough that the disease should haunt certain families. Family infection may thus simulate inheritance. The problem in each case is to distinguish between environmental and true congenital influences. In connection with hereditary tuberculosis three possibilities present themselves: (1) Inheritance of a special susceptibility, metabolic or structural, to tuberculosis; (2) germinal transmission; (3) placental infection.

1. Doubt has sometimes been expressed regarding inheritance of a "tendency." Apart from the legacy of a generally feeble constitution which predisposes to tuberculosis as to other diseases, it is thought by some that there is no inherited inborn liability to tuberculous infection. It is difficult, however, to reconcile this view with what is known of racial resistance and susceptibility to specific infection. The familiar biologic facts concerning heredity and variation attest the existence of individual characteristics of all sorts. It is no more improbable that susceptibility to tuberculosis should exist in certain families than that ordinary sheep should be much more susceptible to anthrax than Algerian sheep. Liability to infection with a particular parasite may as conceivably be a congenital character as the color of the hair or eyes or an aptitude for music or mathematics. In the case of tuberculosis

* Newsholme: Jour. of Hyg., 1906, 6, p. 304.

this may depend upon the transmission of some structural character, such as a peculiarity of the circulation of the lung apices, or upon more obscure metabolic peculiarities. The eminent biologic statistician, Karl Pearson, as the result of a careful statistical inquiry, has concluded that a consumptive predisposition or diathesis is inherited in the same way and with the same intensity that familiar physical characters are inherited.* At the same time it is clear that in any particular case such liability may be difficult to demonstrate, owing—(*a*) to the influence of predisposing causes, (*b*) to the possibility of intrauterine infection, or (*c*) to greater facility of infection from tuberculous relatives.

2. The likelihood of germinal transmission is exceedingly remote. The ovum is practically never infected.† In human semen tubercle bacilli have been found in only a very small proportion of cases, and it does not seem likely that an egg invaded by tubercle bacilli just after fertilization would undergo normal development. In no case has parentally transmitted tuberculosis been traced clearly to the male parent; a tuberculous mother is back of the cases that have been observed (intrauterine infection).

3. Intrauterine or placental infection, although rare, undoubtedly occurs. Perhaps a score of well-established cases in man have been put on record; the number of observed cases in cattle, although not large, is several times as great. In identifying cases of true congenital tuberculosis great care has to be taken to eliminate possibilities of extrauterine infection, such as often occur when young are born from a tuberculous mother; numerous animal experiments have resulted in showing that the young of infected mothers are infected, as a rule, only when they are suckled by the tuberculous parent; if transferred to a healthy foster-mother, they remain healthy. On the whole, placental infection is probably an insignificant item in the totality of tuberculosis.

Tuberculin.—The substance originally known as tuberculin ‡ (T. O.) is prepared by filtering a glycerin-broth culture of the tubercle bacillus and then concentrating upon the water-bath to about

* Pearson, Karl: "A First Study of the Statistics of Pulmonary Tuberculosis," London, 1907.

† One positive observation by Baumgarten is on record, Arb. a. d. path.-anat. Inst., Tübingen, 1891–92, 1, p. 322.

‡ Koch: Deut. med. Wchnschr., 1890–91, 16, 17.

one-tenth its original volume; when stored in a cool dark place, it may retain its properties for months. Many modifications of the original method have been employed. The Bureau of Animal Industry in the United States dilutes with weak carbolic acid the thick syrupy liquid of the concentrate, which in its original condition is difficult to handle in the field. The amount of fluid to be injected for cattle of medium weight is thus increased from 0.25 c.c. to about 2 c.c. Practically all the extracts of the tubercle bacillus contain the poisonous nucleoprotein or its chemical derivatives.

When a small amount of tuberculin is injected into a healthy animal, there is no apparent constitutional disturbance; but when the same quantity is inoculated into an animal with tuberculous lesions, a remarkable selective action appears. There is marked congestion around the tuberculous area, accompanied by necrosis and sloughing off of the tuberculous tissue; fever and other constitutional symptoms also appear.

The *tuberculin reaction* has been made a cardinal feature in the diagnosis of tuberculosis in cattle, and to some extent in man. Its chief practical application is in detecting the disease in dairy cows. The test on cows is made by injecting subcutaneously from 20 to 40 centigrams of tuberculin and noting any change in the temperature of the suspected animal. The normal temperature should be taken every two hours on the day prior to the injection, and after the injection should be taken on that day and on the following day at least every two hours. The normal temperature of the cow may vary considerably,* and should always first be determined; a rise of from 1.5° to 3° C. warrants the inference that the animal is tuberculous; the tuberculin reaction has been often controlled by autopsy, and for all practical purposes is specific and unequivocal. The information afforded by a positive outcome, as a rule, can be relied on implicitly, but a negative reaction is not always proof of the absence of infection. Failure of the test is most likely to occur in advanced and clinically recognizable cases.

The mechanism of the tuberculin reaction, so far as understood, is as follows: The tuberculin acts as a local specific irritant upon the tuberculous foci, producing intense hyperemia and disintegration of the tuberculous mass. This phenomenon has been interpreted as an acceleration of a process going on more slowly under ordinary

* Bulletin No. 7, Bureau of Animal Industry.

conditions, and is regarded as due to the intensifying or stimulating action of the poisonous nucleoprotein, which is the essential ingredient of tuberculin. The disintegration is accompanied by the generation or liberation of toxic substances which enter into the general circulation and produce fever and other constitutional disturbances. The tuberculin reaction is not absolutely specific, but can be produced by various nucleoproteins, yeast nuclein, bacterial proteins, and other substances. Insusceptibility to the tuberculin reaction can be produced by repeated doses, a fact that has been taken advantage of by unscrupulous cattle dealers.

The Ocular Tuberculin Reaction.—In addition to the constitutional changes produced by tuberculin inoculation into a tuberculosis subject, a local reaction also occurs. Von Pirquet * found that the application of tuberculin to the abraded skin caused a characteristic local reaction in tuberculous infants, and no reaction or a very slight one in healthy infants. Corresponding with the fact, brought out by autopsies, of the all but invariable infection, past or present, of older children and adults, the reaction is usually positive for those over the age of eighteen months. Calmette† has made use of this principle in a method more generally applicable for purposes of diagnosis. A solution of tuberculin freed from glycerin by precipitating with alcohol and redissolving in sterile water is instilled into the conjunctival sac. In subjects with active tuberculosis a general congestion of the conjunctiva occurs, and is at its maximum in from six to ten hours, while with the normal individual no reaction takes place. The method has been quite widely tested, and with almost uniformly favorable results. It seems also to be successful in revealing the presence of tuberculosis in cattle.‡

Immunity; Protective and Curative Inoculations.—As a rule, when an attack of tuberculosis is successfully resisted there results little or no increased power of resistance to another attack. In fact, there is reason to believe that a heightened susceptibility frequently follows a previous infection The general weakening of the organism, however, that accompanies a tuberculous infection may mask a slight or transient but real acquisition of immunity.

* von Pirquet: Berl. klin. Wchnschr., 1907, 44, p. 644.

† Calmette: Presse médicale, 1907, 15, pp. 338, 443.

‡ McCampbell and White: Jour. Exper. Med., 1908, 10, p. 232.

Animal experiments by Pearson and Gilliland,* v. Behring, and others have shown that cattle are protected in a marked degree against inoculation with bovine bacilli if they are first injected with the less virulent bacilli of human origin. Vallée† found in an extensive series of experiments upon full-grown cattle and calves that if the animals were fed with a highly attenuated strain of the tubercle bacillus (derived from a horse) they acquired temporary immunity, the more complete the younger the animal. It is possible that treatment with living attenuated bacilli may eventually be found to be a safe and valuable means of protecting human infants. Certain emulsions and extracts of tubercle bacilli ("Bovovaccine"; tuberculase, "T. C.") have been used by v. Behring for protective purposes—it is said with considerable success. Their precise nature and mode of preparation are not yet divulged. An emulsion of the entire living bacilli in 20 per cent. glycerin ("B. E.") has been prepared also by Koch. Its action is very similar to that of the "old" and "new" tuberculins, but it is thought to have greater immunizing power.

A variety of antibodies can be produced by inoculation with tubercle bacilli and their products. Agglutinins and precipitins are quite uniformly generated. Bacteriolytic substances also are possibly formed, but experimental difficulties stand in the way of their ready demonstration. Several observers, notably Maragliano,‡ have found that the serum of immunized animals possesses neutralizing power for the products of the tubercle bacillus. It is still uncertain how far this power is due to the presence in the immune serum of any substance similar to the true bacterial antitoxins. Practically the use of antisera in the treatment of tuberculosis has proved of little value.

The presence of specific opsonins in tuberculosis has been recently utilized in gaging the amount and frequency of the doses of tuberculin. It is thought that by keeping watch of the opsonic index (p. 149) the injection of bacillary extracts and emulsions can be advantageously timed. Trudeau,§ however, does not consider

* Pearson and Gilliland: Proc. Path. Soc., Phila., 1903, 6, p. 105.

† Vallée: Ann. de l'Inst. Past., 1909, 23, p. 585.

‡ Maragliano: Berl. klin. Wochenschr., 1904, 41, pp. 603, 643.

§ Trudeau: Amer. Jour. Med. Sci., 1907, 133, p. 813.

determination of the opsonic index as necessary to control, and in fact prefers to base the treatment on clinical signs, giving a dose at first far below that expected to excite reaction, and gradually increasing the dose as the condition of the individual patient indicates. Jeans and Sellards * also do not consider the opsonic index as sufficiently accurate for the control of tuberculin therapy.

When the "original" or "old" tuberculin ("T. O.") was first introduced by Koch, it was thought to have value as a curative agent, but the sanguine expectations then aroused have not been realized. In lupus, a form of skin tuberculosis, good results have frequently been obtained from the sloughing off of the diseased and necrotic tissue, but in other kinds of tuberculosis the results have not been remarkably successful. A "new" tuberculin ("T. R." = tuberculin residuum) was prepared by Koch in 1897 † by macerating living virulent bacilli and extracting the mass with water, and then making an emulsion of the residuum. More recently Koch ‡ has advocated the use of an emulsion ("B. E."= bacillary emulsion) of the entire substance of pulverized young virulent bacilli in 20 per cent. glycerin. Denys § has introduced the use of the unaltered filtrate from broth cultures ("B. F." = broth filtrate). Some experienced observers at present use by preference the two preparations of tuberculin last named (B. E. and B. F.), either alone or in combination. Whatever the form of tuberculin employed, the governing principle of the tuberculin treatment would seem to be to avoid from the outset the production of a clinical reaction, and to impart, not too rapidly, a tuberculin immunity which will enable the patient to tolerate quantities much larger than the initial dose. An increasing number of favorable results from the discriminative administration of tuberculin is being reported. Among the most noteworthy is the experience of Trudeau, ‖ who has found that from one to fifteen years after discharge from the Adirondack Cottage Sanitarium, out of every one hundred patients in the incipient stage treated with tuberculin,

* Jeans and Sellards: Bull. Johns Hopkins Hosp., 1907, 18, p. 232.

† Koch: Deut. med. Wchnschr., 1897, 23, p. 209.

‡ Koch: Deut. med Wchnschr., 1901, 27, p. 829.

§ Denys: Bull. med. Paris, 1906, 20, p. 772.

‖ Trudeau: Osler, "Modern Medicine," Phila., 1907, 3, p. 434.

seventy-nine were alive; of the untreated, sixty-five; in the advanced stage, sixty-one of the treated, and thirty-six of the untreated were alive.

Other Acid-proof Bacteria.—The once current view that the tubercle bacillus was unique in its resistance to decolorization by acid has been modified by the discovery of a considerable number of micro-organisms possessed of the same characteristic. Some of these, such as the bacillus of leprosy, are closely related biologically to the tubercle bacillus. B. lepræ, however, differs somewhat in form from the tubercle bacillus, is stained with less difficulty, and, owing to the relative infrequency of leprosy and the characteristic occurrence of lepra cells, its resemblance is not likely to engender confusion in matters of practical diagnosis. The smegma bacillus, on the other hand, which is found in the preputial secretion and between the labial folds of the vulva, is often difficult to distinguish from the tubercle bacillus. Its occurrence in the feces and urine, where it has been mistaken for the tubercle bacillus, is said to have sometimes led to serious diagnostic error—even to unnecessary kidney extirpation. In collecting samples of urine, contamination with smegma bacilli may be avoided to some extent by catheterization. The smegma bacillus differs morphologically from the tubercle bacillus slightly, if at all, but is said by some observers to be decolorized, as a rule, by treatment with simple alcohol; it is also said to be shorter and to show minor differences that are likely to be noted by the experienced observer. Such distinctions cannot be safely depended upon, and in doubtful cases guinea-pig inoculations should be made.

A number of other acid-proof bacteria have been isolated from such substances as butter, hay, and dung. These organisms, of which about forty varieties have been described, grow readily at a low temperature upon the ordinary culture-media, often with production of a brownish pigment. They seem to be widely distributed as saprophytes in nature. They have also been observed in sputum in some cases in which the diagnosis of tuberculosis could be excluded on clinical and anatomic grounds. Several observers have found these or similar organisms in man in connection with pathologic conditions, such as bronchitis (Marzinowski *) and pul-

* Marzinowski: Centralbl. f. Bakt., 1900, 28, p. 39.

monary gangrene (Fränkel,* Rabinowitsch†). Animal inoculation does not always surely differentiate these organisms from the tubercle bacillus, since some varieties produce histologic changes closely simulating those of true tubercle formation. The rapid growth of the "grass" and "butter" bacilli in artificial media, in most cases at about 20° C., is the principal differential feature. It is evident that observers may readily fall into error by endeavoring to discover by microscopic examination alone the presence of the tubercle bacillus in such substances as butter or milk. Even the peritoneal inoculation of butter containing the ordinary "butter bacilli" is likely to result in lesions that closely resemble those of tuberculosis. Many of the reported findings of tubercle bacilli in dairy products are therefore of somewhat doubtful value.

* Fränkel: Berl. klin. Wchnschr., 1898, 35, pp. 246, 880.

† Rabinowitsch: Deut. med. Wchnschr., 1900, 26, p. 257.

CHAPTER XXIII

THE BACILLUS OF LEPROSY (BACILLUS LEPRÆ)

In 1848 Danielssen * recognized that certain peculiar cells which were found in leprous tissue were characteristic of leprosy, and as early as 1872 Armauer Hansen † announced his discovery of small rods lying within the "lepra cells." The application of staining methods by Neisser and Hansen ‡ showed these rods to be bacilli; Hansen's discovery of the bacteria in leprosy, therefore, ranks as one of the earliest observations of pathogenic bacteria.

Fig. 95.—Bacillus lepræ. Smear preparation from nasal mucosa (Hansen, Kolle and Wassermann).

Characteristics of the Leprosy Bacillus (B. lepræ).—Morphologically the leprosy bacilli resemble closely the tubercle bacilli. They are long (6 μ), slender rods, usually straight, but sometimes slightly curved. They have no power of independent movement, and are not known to produce spores. The bacilli are sometimes seen lying free in the lymphatic spaces, but the great majority are ensconced in the cells. Their arrangement in the cells is characteristic, several bacilli being usually grouped together in bundles like packets of cigarettes (Fig. 95).

* Danielssen and Boeck: "Traité de la spédalskhed," Tr., Paris, 1848.

† Hansen, Armauer: Norsk Mag. f. Laegevidensk., 1872, 2, p. 1.

‡ Neisser and Hansen: Breslauer ärzt. Ztschr., 1879, No. 20; Archiv d. path. Anat., 1880, 79, p. 32.

The staining reaction of these organisms is much like that of the tubercle bacilli. They stain somewhat more readily than the latter, and also decolorize more quickly, but the difference is not sufficient to serve for differential diagnosis. The presence of large numbers of bacilli within the cells, together with the clinical features, makes it possible ordinarily to distinguish leprosy from tuberculosis without difficulty. Sections of tissue may be left twenty-four hours in carbol-fuchsin, then decolorized with hydrochloric acid and alcohol, and finally counterstained with aqueous methylene-blue.

It would be futile to recapitulate the attempts that have been made to cultivate the bacillus of leprosy. It is sufficient to state that up to the present these attempts, made with a variety of media, and under many conditions, have been wholly unsuccessful. The reported announcements of success by some observers have not been confirmed by others, and, as the matter now stands, saprophytic growth on the part of the leprosy bacillus is entirely unknown.

Pathogenesis.—Although any organ or tissue may be attacked with varying results, two distinct types of leprosy are usually recognized—the nodular and the anesthetic. The former, which is the more acute, is characterized by the development of masses of granulation tissue, the so-called leproma, which may appear superficially in different parts of the body, and by their growth and coalescence cause terrible distortion and mutilation. The anesthetic type, or nerve leprosy, progresses more slowly than the other form, the average duration of the cases being nearly twice as long (eighteen years), some being known to extend over thirty-five to forty years; atrophy of the muscles and other trophic disturbances accompany the nerve lesions.

In both forms of leprosy the Hansen bacillus is found in all cases: in enormous numbers, as a rule, in the lesions of nodular leprosy; less abundantly in the anesthetic type. As already stated, it is the prevailing opinion among students of this disease that while a few bacilli occur free in the lymphatic spaces, the great majority are contained within the cells.* The nucleus itself is not invaded. Unna † maintains that they lie exclusively in the lymph-spaces;

* Hansen is of opinion that all the bacilli are in the cells originally and only appear in the lymph-spaces when the normal relations are disturbed.

† Unna: Deut. med. Wchnschr., 1886, 12, p. 123.

other observers (Leloir)* believe that they occur partly in one partly in the other situation. Almost any organ or tissue may be the site of a leprous growth. Bacilli have been found in practically all parts of the body. The kidneys are usually invaded, the liver and spleen always. The bacilli have been seen by several observers in the cells of the central nervous system; they are sometimes encountered in the blood, generally in the leukocytes, but occasionally free (Hansen).

When bits of leprous tissue are introduced subcutaneously into an animal, a slight local reaction sometimes occurs, but there is no multiplication of bacilli, and no production of true leprous lesions. Evidence that the disease can be transmitted to the lower animals under any natural or artificial conditions is completely lacking; the only situation in which the bacillus of leprosy is known to find suitable conditions for development is the human body.† Here the period of incubation is a long one (often two or three years, in some cases much longer—twenty-seven years), the invasion is strikingly localized, and the conditions necessary for successful communication seem to concur but rarely.

Evidence of the direct inoculability of leprosy from man to man is quite inadequate. Many attempts to infect healthy persons have been made and have failed, and one often-cited instance of successful inoculation is by no means unimpeachable. In the case of the criminal Keanu in the Hawaiian Islands, reported by Arning,‡ implantation of material from a leprosy nodule was followed by the development of true leprosy, which terminated fatally six years after inoculation. The experiment, however, did not exclude the important source of error involved in the facts that Keanu was the native of a country in which leprosy was common, that he had lived among lepers, and that members of his family were lepers.

The indirect evidence of transmission is more significant. Manson§ cites the case of a leper, an Irishman, who acquired his disease in the West Indies. On his return to Ireland his bed was shared

* Leloir: Comp. rendu Acad. Sci., 1885, 101, p. 97.

† Nicolle, however, claims to have produced by inoculation typical leprous nodules in a monkey. (Sem. médicale, 1905, 25, p. 116.)

‡ Arning: Archiv f. path. Anat., 1893, 134, p. 319.

§ Manson: "Tropical Diseases," London, 1900, p. 448.

by his brother, who, moreover, sometimes wore the leper's clothes. The latter, who had never been in any foreign country, became, in time, an undoubted leper. In this case communication from one person to another is practically demonstrated.

Mode of Transmission.—The numerous cases in which healthy persons, such as asylum attendants, have been more or less in contact with lepers for long periods without contracting the disease have induced some observers to deny the possibility of contagion. Another explanation of this freedom from contact infection, and one more in accordance with other observations, can, however, be advanced. This is that the conditions necessary for successful infection are rarely met with, and that consequently infection does not take place simply by association of a leprous with a sound individual. The conditions that render transmission of the disease possible are entirely unknown; they may concern the virulence of the infecting bacillus, the availability of a suitable portal of entry, or some peculiar and rarely occurring state of receptivity on the part of the individual attacked. The cardinal point in the epidemiology of leprosy appears to be that intimate contact with a leprous individual or residence in a locality where leprosy is endemic is a necessary condition of infection. There is no valid evidence of the occurrence of the bacillus of leprosy outside of the human body, and in view of all the facts there seems no escape from the doctrine of direct contagion.

One way in which the bacillus may leave the body is in the nasal mucus. Sticker * and other observers have found bacilli in the secretions of the nose in a large proportion of cases. Bacilli may sometimes be discharged from the mouth or nose in small particles of mucus driven out by violent coughing or sneezing. In the opinion of many writers, the mucous membrane of the nasopharynx is the point at which the bacteria are introduced into the body, as well as the chief source from which infection is spread.

Much light is thrown on the contagious character of leprosy by the success that has attended the isolation and segregation of leprous patients. The experience of Norway has shown that a careful but not unduly rigorous system of separation has been accompanied by a diminution of the number of cases from 2870 in 1856 to 577

* Sticker: Deut. med. Wchnschr., 1897, 23, v, p. 219.

in 1900. The circumstance that infection does not invariably follow chance contact or association should not, therefore, lead to neglect of the facts that leprosy is a bacterial disease; that up to the present the specific germ has not been found under natural conditions, except in the human body; and that, so far as is known, the leper himself is the only means by which leprosy spreads.

From the fact that a number of cases of leprosy often occur in the same family the disease has been regarded by some as "hereditary." The question of the "inheritance" of a bacterial disease has already been discussed in connection with tuberculosis, and the case as regards leprosy is very similar. Germinal infection (of the ovum or sperm), if it occurs at all, is probably very rare, most lepers becoming sterile early in the disease. Intrauterine infection, although it has been reported, is not common. Hansen has called attention to the remarkable fact that none of the children of one hundred and seventy Norwegian lepers who have from time to time migrated to North America have become diseased. It seems reasonable to suppose, however, that a special tendency to contract leprosy may be inherited, just as any other bodily peculiarity.

CHAPTER XXIV

THE GLANDERS BACILLUS (BACILLUS MALLEI)

Glanders is a disease seen, as a rule, only in the solipeds (horse, mule, ass), but occasionally transmitted to other domestic animals, to wild animals, and to man. As in so many other diseases, the early history of this malady is marked by lively oscillations of opinion as to its infectious nature. The doctrine of the spontaneity and non-infectivity of glanders received strong support as late as 1830–40, especially from the famous Alport school of veterinarians in France. In practice the prevalence of this view was attended with disastrous consequences. In 1837 Rayer * demonstrated that the horse could be infected by inoculating it with material derived from a case of glanders in a human subject. Owing to the high reputation of the author this experiment made a deep impression, and although a similar experiment had been successfully performed by others prior to this time, Rayer's work may be said to mark the downfall of the dogma of spontaneity.

The specific germ of glanders was discovered in 1882 by Löffler and Schütz,† whose results were soon confirmed and extended by Kitt,‡ Weichselbaum,§ and others.

Morphologic and Cultural Characters.—The glanders bacillus, or B. mallei, is a small rod, straight or slightly curved, usually with rounded ends, and often of irregular contour. It is about the same length as the tubercle bacillus, but is shorter and thicker than the latter (Fig. 96). Rather wide variations in size are observed; the following dimensions may be taken as the average range: length, 2 to 5 μ; breadth, 0.5 to 1 μ. Power of independent movement is absent. The organism is not known to form spores, although there has been much discussion concerning the nature of certain

* Rayer: Mém. Acad. de méd. Paris, 1837, 6, p. 625.

† Löffler and Schütz: Deutsch. med. Wchnschr., 1883, 9, p. 197.

‡ Kitt: Jahresber. d. k. Centralbl. Tierartz.-Sch., München, 1883–4.

§ Weichselbaum: Wien. med. Wchnschr., 1885, 35, p. 665.

granules and irregularly staining portions of the cell protoplasm. It is now generally admitted that, whatever may be the physiologic significance of these unevenly stained elements, they are not to be regarded as true spores. No increased power of resistance is shown by cultures containing the granules or coccus-like bodies. In cultures the bacilli frequently occur in pairs, sometimes in short chains. Long filaments with swollen ends and true branching have been seen by several observers and have induced some writers to rank the glanders bacillus with the trichomycetes. (Compare the tubercle bacilli, p. 337.)

B. mallei stains with the ordinary aqueous anilin dyes, although not very readily. The best results are obtained with stains containing alkali, or a mordant such as carbolic acid (for example, Löffler's alkaline methylene-blue, Ziehl's carbol-fuchsin, etc.). Decolorization takes place easily on the application of alcohol or dilute acid; the color is lost also by Gram's method.

Fig. 96.—Bacillus mallei. Pure culture from glucose-agar. Carbol-fuchsin; × 1200.

Growth occurs on the ordinary media, but is materially aided by the presence of glycerin. Temperatures below 22° C. are unfavorable, the optimum being about 37° C. A slightly acid reaction of the medium is rather favorable than otherwise. Save on potato, the growth presents little that is characteristic. On this medium at 37° C. a tenacious, transparent, honey-like layer is formed, which in time takes on a deeper brownish hue. Often, but not invariably, the potato around the growth becomes tinged a greenish yellow, not unlike the coloration produced by some cultures of B. pyocyaneus.

In nutrient broth a uniform turbidity is produced, and a white,

heavy, viscous sediment collects at the bottom of the tube. On agar and glycerin-agar a whitish, translucent streak is formed, with crenated edges, and possessed of a tenacious consistency. Gelatin is not liquefied. Milk is slowly curdled with acid production by some cultures, but the statements of different observers are not in accord respecting the action on this medium; different cultures doubtless behave differently (Wherry *).

As in the case of many other parasitic bacteria, growth does not always take place readily when the glanders bacillus is first transplanted from the animal body to artificial culture-media. After a few transfers, however, the saprophytic habit is firmly established, and by reinoculating at suitable intervals upon glycerin-agar of a uniform reaction (Wherry) and keeping at a low temperature little difficulty is experienced in maintaining living cultures.

Toward physical and chemical agents B. mallei manifests slight resistance, being readily destroyed by heat and antiseptics. Desiccation experiments have not given uniform results, the reported longevity under drying ranging from a few days to several months. In this particular pure cultures are said to be more resistant than the bacilli in the nasal secretions from diseased animals (Löffler,† Nowikoff ‡).

Pathogenesis for the Lower Animals.—Under natural conditions the horse chiefly is found affected, but cases are occasionally observed in the carnivora (cats, dogs, menagerie animals) and in goats and sheep. Swine and pigeons are slightly susceptible. Cattle and the house-rat are immune. Rabbits and guinea-pigs are susceptible to inoculation.

Glanders manifests itself in an acute and a chronic form. The acute form is ushered in usually by a chill and the appearance of a high temperature in advance of any local manifestation. In a few days the mucous membrane of the nose is inflamed and becomes studded with nodules, the lymphatic system becomes largely implicated, and edematous swellings appear in various parts of the body. General symptoms become more grave, and death follows in

* Wherry: No. 24, Publications of Government Laboratories, Manila, November, 1904, p. 24.

† Löffler: Arb. a. d. kais. Ges., 1885, 1, p. 141.

‡ Nowikoff: Arch. d. Sci. vét., 1895.

from eight to thirty days (Nocard *). The mule, and especially the ass, suffer commonly from the acute disease. The chronic form is the more usual type in the horse (90 per cent.). A great variety of symptoms and lesions have been noted in the latter animal, and the disease pursues most diverse courses in different individuals. The nasal membrane is often affected, and there is a profuse and infectious catarrhal discharge. Cutaneous glanders is known by veterinarians as *farcy*, the thickenings of the superficial lymphatics being termed "farcy buds" or "farcy pipes." In all forms of glanders there is a tendency to the production of nodules, which soften and pass over into ulcers.

The glanders nodule has been considered by some writers to be structurally similar to the nodule formed by the tubercle bacillus (p. 345), but most observers are agreed that the former is a degenerative rather than a proliferative formation, and that it is radically different from the tubercle. The acute and chronic types run into one another, the latter frequently terminating in an acute attack. Experimental inoculation with pure cultures has given positive results, not only in the horse, in which the characteristic features of the disease are reproduced, but in guinea-pigs, field-mice, and other small rodents. House-mice and white mice show a high but not absolute resistance, in contrast to the great susceptibility of field-mice. The guinea-pig responds to inoculation in a typical fashion, and this has been taken advantage of in effecting the differential diagnosis of glanders (p. 375). Both in the natural and in the experimental infection the bacteria are found chiefly in the nasal secretions and in the contents of the young nodules; in the older ulcers they are relatively few in number. The blood, as a rule, contains glanders bacilli only in acute general infection.

Pathogenesis for Man.—Veterinarians and others having to do with the care of horses are the most liable to contract glanders. Freshly isolated cultures are highly virulent, and a number of cases with fatal termination have occurred among laboratory workers. The acute form of the malady is the more common in man: most cases terminate fatally within two to three weeks, sometimes within a few days of their inception. As in the horse, the mucous membrane of the nostrils, although not invariably affected, is a place of predi-

* Nocard: "Les maladies microbiennes des animaux," 2d ed., Paris, 1898.

lection for the glanders nodules and ulcers. Occasionally the chronic form may appear and linger for months or even years, with spreading ulceration and other features closely resembling those observed in the horse (Fig. 97). Recovery from chronic glanders may take place, or the disease may pass into the acute stage.

Path of Entrance.—The avenue by which the glanders bacillus usually enters the body of the horse has not been clearly determined. The intact skin probably rarely, if ever, permits entrance, but a slight wound or injury offers a ready portal, as attested by experi-

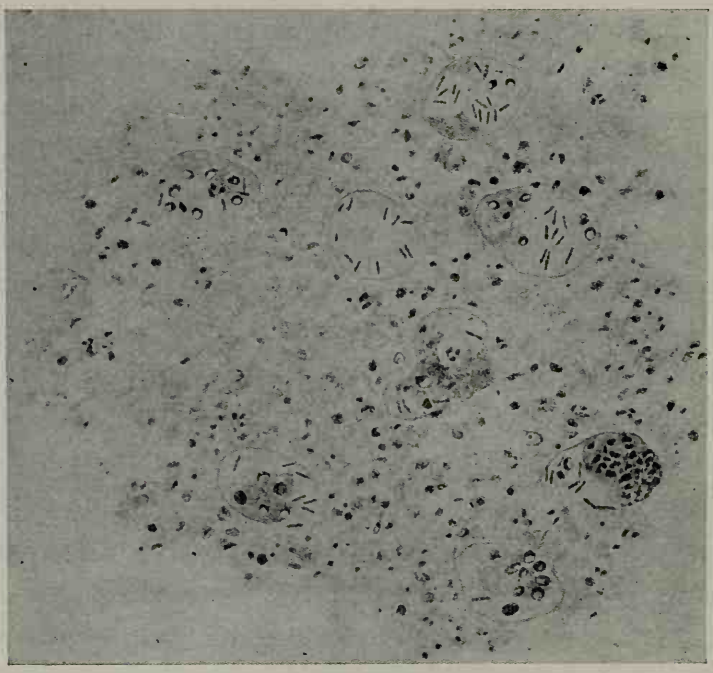


Fig. 97.—Bacillus mallei in giant-cells and exudate of human lungs (Coleman and Ewing).

mentation. The mucous membrane of the nose, especially if slightly abraded, may become the portal of entry, as may the intact conjunctiva, which, as shown by Conte,* can be infected by contact with infectious material in two to four hours, sometimes in thirty minutes. Infection by inhalation must be rare, to judge from animal experiments, if, indeed, it ever occurs. According to Nocard, who made a special study of the mode of infection, penetration takes place by way of the alimentary tract in the great

*Conte. Revue Vétérin., 1893, p. 568.

majority of cases. There is weighty experimental and other evidence in support of this view.

In man the alimentary tract is certainly not the ordinary channel of entrance; cases are on record of the ingestion of meat from glandered animals without resulting infection. Inhalation likewise hardly enters into consideration. Probably infection through a scratch or other break in the skin is the usual origin of human cases.

Diagnosis.—In prebacteriologic days chronic glanders in the horse was frequently separated from other diseases only with difficulty and a considerable measure of uncertainty. At present the diagnosis of glanders is greatly facilitated by: (1) guinea-pig inoculation; (2) the mallein test; (3) the agglutination method.

1. *Guinea-pig Inoculation.*—A male guinea-pig is injected intraperitoneally with fragments of diseased tissue, scrapings from ulcers, or some of the nasal discharge from a suspected animal. A positive reaction is shown by the testicles becoming red and swollen, usually on the second or third day (Straus*). Together with the orchitis (inflammation of the tunica vaginalis or investment of the testicle) there are severe general symptoms which usually culminate in twelve to fifteen days. Grayish nodules are usually found in the spleen and other internal organs. The test is not absolutely specific, for Nocard and Kutscher † have shown that an analogous orchitis may be produced by other organisms besides the glanders bacillus. It is often, however, of value, especially when, for one reason or another, other tests are inapplicable.

2. *The Mallein Test.*—Mallein is the concentrated glycerin broth in which the glanders bacillus has grown; it is prepared in the same manner as tuberculin. The mallein reaction consists in a rise of temperature, accompanied by a pronounced local swelling, and in many cases, although not invariably, by more or less profound constitutional disturbances. Injection of the mallein (the size of the dose varying according to the concentration) into a glandered horse is followed by the signs above noted, while in an animal not infected with glanders the temperature is slightly or not at all affected and

* Straus: Archives de méd. expér., 1889, 1, p. 489; Comp. rend. Acad. Sci., 1889, 108, p. 530.

† Kutscher: Ztschr. f. Hyg., 1895, 21, p. 156.

the general symptoms are absent. The temperature of the suspected animal should be taken at two-hour intervals before the injection is made, and after the injection as often, at least, as on the ninth, twelfth, fifteenth, and eighteenth hours. The increase of temperature in glandered horses varies from 1.5° to 2.5° C. above the normal, and is distinctly high on the second day after injection. Healthy horses often show a distinct temperature increase on the first day after inoculation, but, as a rule, this disappears quickly. In the use of mallein, as in the tuberculin test, care must be taken to exclude other influences that disturb the normal temperature relations. Experienced observers lay much stress upon the appearance of swelling at the seat of inoculation. In a glandered animal the tumefaction is large, hot, and painful; it increases in size up to twenty-nine to thirty-six hours, persists for about a week, and gradually disappears. In a healthy animal a swelling may occur, but it is never large and vanishes within twenty-four hours.

There is complete agreement among veterinarians regarding the diagnostic value of mallein. The reaction is specific, is usually sharp and decisive in character, and almost never fails to reveal the presence of infection. Nocard has expressed himself very emphatically: "A complete mallein reaction is unequivocal; the animal that reacts is glandered. An animal which does not react to an injection of mallein is not glandered, whatever the character of the symptoms."

3. *The Agglutination Method* (Macfadyen *) is gaining in favor for the diagnosis of glanders, and is used officially in Prussia and Austria. The serum of normal horses agglutinates in dilutions of from 1:200 to 1:300, and the reaction is specific only when rather high dilutions (1:500 to 1:3200) are used; the serum from sound animals, however, sometimes agglutinates the glanders bacillus in a dilution as high as 1:500. Occasionally the reaction fails to appear in the serum of glandered animals. The test is liable to the usual difficulties and sources of error in the hands of an unskilled observer (p. 158). Moore † uses a suspension of B. mallei in carbolized salt solution prepared from a glycerin-agar culture, killed by heating to 60° C. for two hours.

* Macfadyen: Jour. Comp. Path. and Therap., 1896, 9, p. 322.

† Moore: Jour. Infect. Dis., 1907, Suppl. No. 3, p. 85.

Immunity.—Permanent immunity to glanders can neither be conferred by an attack of the disease nor produced by any artificial means. Nocard fed with infectious matter three horses which had previously recovered from the disease, and found that these animals showed no superior resistance when compared with a healthy control animal. Chronic glanders may exist for years, and is in no wise a warranty against the sudden development of an acute attack.

No very potent or characteristic toxic substance has been obtained from cultures of the glanders bacillus, and attempts at immunization with the products of this organism have been eminently unsuccessful. It is stated by a number of observers that repeated injections of mallein will exercise a curative action upon certain forms of recent infection, but mallein is without immunizing power. The serum of animals treated with mallein injections and the serum of naturally immune animals, such as cattle, are, according to most observers, totally devoid of any preventive or curative value.

The most that has been accomplished in the direction of immunization is a very moderate augmentation of resistance in dogs injected with small non-fatal amounts of living cultures (Straus).

CHAPTER XXV

OTHER PATHOGENIC BACILLI

Bacillus Pyocyaneus

The blue or blue-green stains that sometimes appear upon surgical dressings long ago attracted the attention of observers, and even before the cause of the phenomenon had been discovered, Fordos * carried out some important investigations upon the nature of the coloring substance. In 1882 Gessard † proved that the pigment was the product of a specific micro-organism, B. pyocyaneus, which he was able to isolate in pure culture.

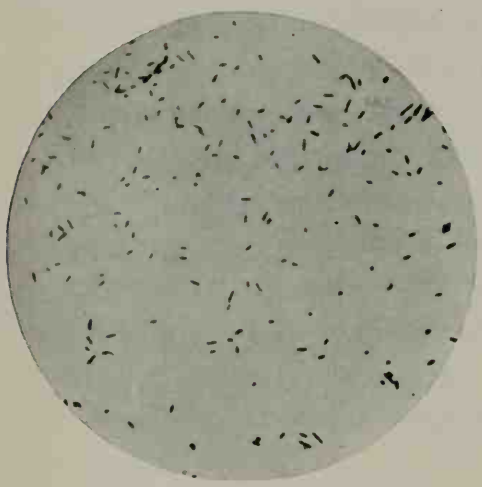


Fig. 98.—Bacillus pyocyaneus. Pure culture on agar. Fuchsin stain. Zettnow prep. (Kolle and Wassermann).

Morphology and Cultural Characters.—The cells of B. pyocyaneus vary considerably in size and proportion, but appear usually as small, slender rods, frequently united in pairs and short chains (Fig. 98). A single flagellum is attached to one end, and the organism is actively motile. Spores have never been observed. Gram's stain is negative.

B. pyocyaneus grows readily on all the ordinary culture-media. Gelatin is quickly liquefied, and freshly isolated cultures impart to this medium the characteristic blue-green coloration. Upon agar a yellowish-white surface growth usually develops, the agar itself being richly colored. Broth is rendered turbid, a heavy flocculent sediment is formed, and a tenacious surface pellicle. Indol is produced. Growth on potato is generally luxuriant and of a brownish color; the potato itself is tinged green by freshly isolated strains.

* Fordos: Comp. rend. Acad. d. Sci., 1860, 51, p. 215.

† Gessard: La pyocyanine, Thèse, Paris, 1882.

Milk is quickly curdled and shows an alkaline reaction; in old cultures the casein is digested.

Products of Growth.—Those cultures of B. pyocyaneus that have been recently isolated from the animal body generate two pigments: a fluorescent green pigment, apparently identical with that produced by a number of common water bacteria (B. fluorescens liquefaciens *et al.*), and a more characteristic deep blue pigment, known as pyocyanin, which can be extracted from solution by chloroform. Ledderhose * ascribes to pyocyanin the formula $C_{14}H_{14}N_2O$. The pigment has no poisonous qualities, as shown by animal experiments. Pyocyanin oxidizes to a dark brown or even black pigment in old cultures, and in strains that have long been under cultivation the brownish color appears without previous development of the blue color. The conditions that determine both the formation of the fluorescent pigment and of the pyocyanin have been exhaustively studied. Oxygen is essential. Sulfate and phosphate are necessary to the formation of the fluorescent pigment, but small quantities of pyocyanin may be formed in the absence of these salts. The enzymes secreted by B. pyocyaneus have also often been the object of special investigation. The sterile filtrates of this organism dissolve gelatin and fibrin; Breymann† found an enzyme that coagulated and peptonized milk and was closely bound to the bodies of the bacilli; Emmerich and Löw‡ carried out a long series of observations on a thermo-stabile substance called by them pyocyanase, to which they attributed great importance in immunizing against and in curing certain infections. The results of these latter writers have not been confirmed. The filtrates of B. pyocyaneus likewise possess hemolytic power, but this property seems to be due simply to the alkalinity of the filtrate and not to the presence of any specific "pyocyanolysin" (Jordan §).

Broth cultures of B. pyocyaneus are toxic especially for guinea-pigs. According to Wassermann, this toxicity is due, not to an endotoxin, but to the presence of a true soluble toxin, which, however, is very resistant to heat.

* Ledderhose: Deut. Ztschr. Chirurg., 1888, 28, p. 201.

† Breymann: Centralbl. f. Bakt., Orig., 1902, 31, p. 481.

‡ Emmerich and Löw: Ztschr. f. Hyg., 1899, 31, p. 1; 1901, 36, p. 9.

§ Jordan: Jour. Med. Res., 1903, 10, p. 31.

Broth cultures grown at 37° C. assume after a few days a slimy, viscid character, due to the production of "pseudo-mucin."* Later the cultures become less slimy and develop true mucin.

Pathogenicity.—For some time after its discovery B. pyocyaneus was generally regarded as a harmless saprophyte, or at worst an organism of slight pathogenic power. Evidence has gradually accumulated that this view is incorrect, and that B. pyocyaneus is causally associated with a great variety of suppurative and other affections in man. Apart from the many doubtful cases where B. pyocyaneus is found mixed with streptococci, staphylococci, and other organisms, and where its share in inciting pathologic processes is therefore problematic, there are numerous instances on record where little or no question exists as to its etiologic rôle. It has been found by a number of observers in pure cultures in abscesses in different parts of the body, especially in the middle ear. Cases of endocarditis and pneumonia have also been met in which B. pyocyaneus seemed to be the sole responsible organism. A generalized and fatal form of pyocyaneus infection has been observed by a number of investigators,† and the bacillus has been found in the blood during life.‡ Lartigau§ found B. pyocyaneus constantly present in the intestinal discharges of patients during a dysentery-like epidemic, and the same organism was also present in abundance in drinking-water which seemed, on epidemiologic grounds, to be implicated in the outbreak. On the whole, therefore, there is no doubt that under certain conditions B. pyocyaneus is pathogenic, even gravely so, for man.

Intraperitoneal injection of $\frac{1}{10}$ of a loop of fresh agar culture will kill a guinea-pig acutely in twenty-four hours. Smaller amounts are also fatal, but less rapidly. Subcutaneous inoculation produces a marked local reaction and is less deadly than intraperitoneal. The symptom-complex presents nothing especially characteristic. Rabbits are not as susceptible as guinea-pigs; mice and pigeons are less so. Immunity may be produced by small, non-fatal doses.

* Rettger: Jour. Med. Res., 1903, 5, p. 101.

† See, for example, Rolly, Münch. med. Wchnschr., 1906, 53, p. 1399.

‡ Brill and Libman: Amer. Jour. Med. Sci., 1899, 118, p. 153.

§ Lartigau: Jour. Exper. Med., 1898, 3, p. 595.

Bacillus Lactimorbi

A peculiar disease of man, commonly known as milksickness, prevailed in certain sections of the United States during the years of pioneer settlement (1800–1860). It was early seen to be connected always with the use of milk, butter, or meat from animals affected by a disease called trembles or slows. On epidemiologic grounds milksickness and trembles may be pronounced to be identical. One of the most singular features of the disease is its geographic limitation, for it has never been known outside of the United States, or, as a rule indeed, east of the Alleghenies. Cultivation of the soil favors its disappearance, and in recent years it has become practically extinct in those States of the middle west where it was once a rather common cause of illness and death. A bibliography of the earlier articles on milksickness has been given by Schuchardt.*

In 1907 a new focus of milksickness was discovered in New Mexico, and a characteristic bacillus was isolated from the bodies of several animals dying from the disease. This bacillus, to which the name of B. lactimorbi has been given, is considered to be the cause of trembles, (1) because it is found in the intestinal contents of affected animals and in man, (2) because it is sometimes found in pure culture in the internal organs of fatal cases, (3) because when fed in large quantities to dogs and calves it reproduces, at least in part, the typical symptoms and lesions of the "slows."†

B. lactimorbi is an aërobic, spore-forming bacillus, somewhat smaller than the anthrax bacillus. Deeply staining metachromic granules are usually present in the cells grown on artificial media, but are not found in smears made directly from the organs or tissues. Considerable variation in morphology has been observed, long filamentous forms being not uncommon. Growth takes place on the ordinary culture-media. On agar slants the growth is at first thin and veil-like, but later may become almost as profuse as that of B. typhosus. Gelatin is liquefied slowly, the first evidence of liquefaction being detected in about eight to ten days; a putrescent odor is usually generated in this medium. Blood-serum is not liquefied. Milk is usually rendered alkaline, but the change takes place slowly

* Schuchardt: Janus, 1897–1898, 2, pp. 437, 525.

† Jordan and Harris: Jour. Amer. Med. Assoc., 1908, 50, p. 1665; Jour. Infect. Dis., 1909, 6, pp. 401, 505.

and with some strains lightly seeded not at all. No growth occurs on potato. On agar plates the colonies resemble those of streptococcus, but are usually somewhat more vigorous, and if the agar is fresh, film-formation occurs. Some strains show a yellowish-brown tinge in old cultures.

Fed in large quantities to dogs, B. lactimorbi leads to the evacuation of blood-flecked mucus in the stools, in which the bacillus is found in large numbers. The animal appears weak and irritable, and the bark sometimes becomes harsh and raucous and sometimes very feeble. The liver is often soft and friable, and in section shows cloudy swelling. The kidney and heart are also affected.

The calf when fed with B. lactimorbi becomes weak and easily tired. When exercised, it is apt suddenly to stumble and fall. Changes in the liver, intestine, and other internal organs are similar to those observed in animals dying of the "slows."

Bacillus Proteus

Bacillus proteus (Proteus vulgaris, Bacterium vulgare), first described by Hauser,* is one of the most common bacteria in soil and water rich in organic matter, and in decaying and decomposing substances everywhere. It is perhaps to be identified with "the bacterium of putrefaction" or the so-called B. termo of early writers. The name Proteus is often applied to a closely related group of bacilli rather than to a single species. Morphologically the bacilli in this group are rather long and slender and show a marked tendency to form filaments. They all ferment dextrose and saccharose with gas production, but rarely produce gas in lactose. The gas in dextrose broth is a mixture of H and CO_2, the former being in excess. Gas production, as a rule, is not so vigorous as with B. coli.† The members of this group are, for the most part, vigorously proteolytic, rapidly liquefying gelatin and blood-serum, and precipitating

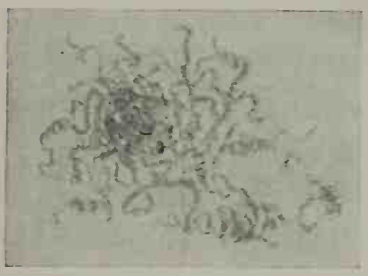


Fig. 99.—Bacillus proteus colony (Lehmann and Neumann).

* Hauser: "Ueber Fäulnissbakterien," Leipzig, 1885.

† Smith, Theobald: "The Fermentation Tube," Wilder Quarter Century Book, p. 212.

and dissolving casein.* Milk is curdled rather slowly, with acid reaction. Some varieties do not liquefy gelatin, others liquefy it very slowly. Yellow pigment is produced by a number of bacteria found in water and closely related to the Proteus group (*e. g.*, B. ochraceus). **B. cloacæ** is an organism allied to the Proteus type, which is frequently found in sewage and polluted water. It liquefies gelatin very slowly and ferments dextrose broth with an excess of CO_2 over H (5 : 1 to 2 : 1).†

B. proteus has been found in connection with a variety of pathologic conditions in man. Certain outbreaks of food-poisoning have been attributed, on more or less convincing evidence, to infection with this organism.‡ Metschnikoff regards it as the usual cause of infantile diarrhea. An acute and apparently specific infectious disease, characterized by fever and jaundice, and known as infectious jaundice, *Weil's disease*, has been believed by Jeger§ to be due to infection with a variety of B. proteus (B. proteus fluorescens), and this belief is shared by others who have had opportunity to observe this pathologic condition. It has been often noted that Weil's disease appears in persons who have been in contact with decomposing animal matter, foul water, etc.

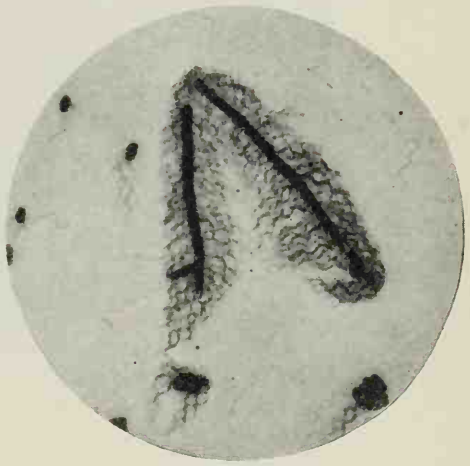


Fig. 100.—Bacillus proteus, showing flagella (Migula).

When virulent strains of B. proteus are injected subcutaneously into animals, they cause purulent abscesses. If large numbers are injected into the peritoneal cavity, they produce fatal infection in mice, rabbits, and dogs; the filtrate of cultures has little effect.

* Jordan: Jour. of Hyg., 1903, 3, p. 8.

† Jordan: Rep. Mass. State Board of Health, 1890, p. 836; Jour. of Hyg., 1903, 3, p. 10.

‡ See, for example: Booker, Centralbl. f. Bakt., 1891, 10, p. 284; Ohlmacher, Jour. Med. Res., 1902, 7, p. 411; Dieudonné, Münch. med. Wchnschr., 1903, p. 2282.

§ Jaeger: Ztschr. f. Hyg., 1892, 12, p. 525.

The Morax-Axenfeld Diplobacillus

A small bacillus, about 2 μ by 1 μ, first described by Morax*

Fig. 101.—Morax-Axenfeld diplobacillus. Smear taken from conjunctiva (Brown Pusey).

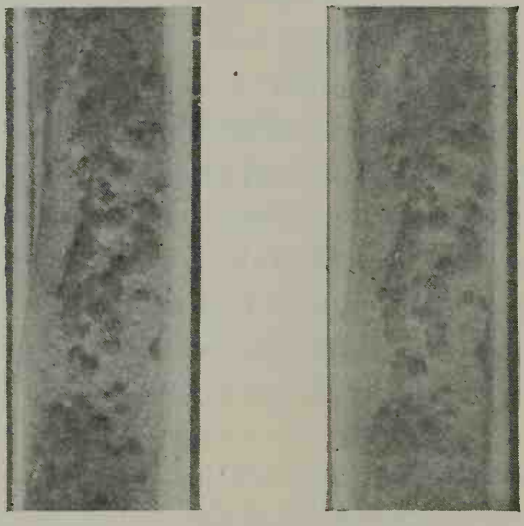


Fig. 102.—Stereoscopic photograph of a culture of the Morax-Axenfeld diplobacillus on blood-serum (Brown Pusey).

(1896), and independently by Axenfeld, is responsible for infections

* Morax: Ann. de l'Inst. Past., 1896, 10, p. 337.

of the conjunctiva and cornea in man. The particular eye trouble with which this bacillus is associated is widely distributed, and has been reported in Europe, Africa, and North America. The organism grows readily on Löffler's blood-serum, where it produces in sixteen to twenty-four hours a rather characteristic picture (Fig. 102). The serum is liquefied in a series of pits which are at first separate, but later run into one another. On agar, gelatin, and the other ordinary laboratory media no growth takes place. Stained preparations from cultures show considerable variation in the size of the bacilli; pairs are frequently observed and occasionally short chains (Fig. 101). Involution forms are common after forty-eight hours. The bacilli lose the stain by Gram's method.

So far as known, this organism is pathogenic only for the human eye. A blepharo-conjunctivitis, either chronic or acute, is the most common condition, but severe inflammation of the cornea is also produced.* Treatment with a 0.25 per cent. zinc sulfate solution is specific and produces a rapid cure, while silver salts are without effect (Pusey).

* Pusey: Jour. Amer. Med. Assoc., 1906, 47, p. 255.

CHAPTER XXVI

THE PATHOGENIC SPIRILLA

Spirillum Cholerae (Vibrio Cholerae)

Although Asiatic cholera has doubtless smoldered endemically in parts of India for many centuries, the year 1817 marks its first considerable extension beyond the borders of that country. Europe was first invaded in 1831, since which date several great epidemics have carried the disease over a large part of the civilized world. The specific germ was discovered in 1883 by Koch* in the intestinal contents of cholera patients.

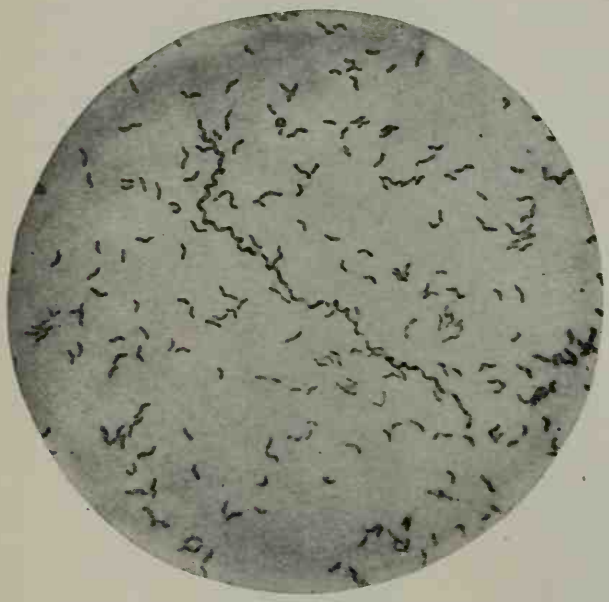


Fig. 103.—Spirilla of Asiatic cholera. Broth culture two days old. Fuchsin stain. × 1000 (Fränkel and Pfeiffer).

Morphology.—In stained preparations the cholera spirillum appears as a short, slightly curved and twisted rod, the so-called "comma bacillus" (Fig. 103). In most cultures some short spirals or S-shaped forms may also be observed. The long, straight, and spiral threads formed in the pellicle of liquid gelatin cultures are usually regarded as involution forms. Cultures that are long transferred on agar often lose the curved form and appear as straight rods, but resume the more characteristic shape when passed through animals. A single flagellum is present at one end of the true S. choleræ. Some writers have described cholera germs as possessed of a tuft of several

* Koch: Berl. klin. Wchnschr., 1884, 21, p. 477; Brit. Med. Jour., 1884, 2, pp. 403, 453.

flagella, but the organisms observed to be so endowed were probably not the true cholera spirilla, but some of the numerous related varieties (Kolle). Active motility is manifested. True spores are not found. The cholera spirillum stains readily with the ordinary anilin dyes. It is decolorized by Gram's method.

Cultural Characters.—Growth occurs abundantly on the ordinary culture-media, a distinctly alkaline reaction, however, being essential. Upon gelatin plates at 20° to 22° C. the growth is quite characteristic. The colonies are plainly visible to the naked eye after twenty-four hours, and are at first round, with an even contour, later becoming irregular; under a low power of the microscope the colony presents a rough, granular appearance, as if the surface were covered with fine particles of glass (Fig. 104). A little later — within forty-eight hours—liquefaction of the gelatin sets in, and the colony sinks into a funnel-shaped depression whose area rapidly extends. This typical colony formation occurs in most of the freshly isolated cultures, but considerable variation sometimes takes place; in old laboratory cultures liquefaction is tardy and the colonies have a brownish tinge.

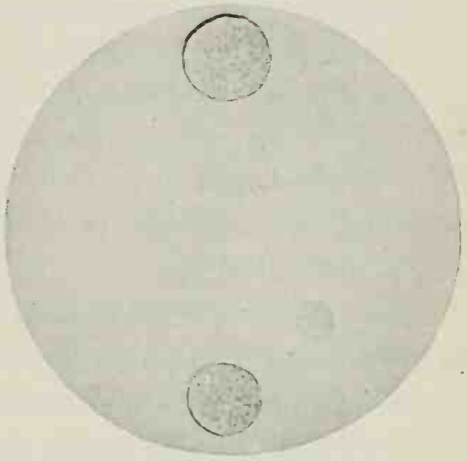


Fig. 104.—Colonies of the cholera spirillum. Gelatin, twenty-two hours old; × 100. Zettnow prep. (Kolle and Wassermann).

Stab cultures in gelatin often develop a small, turnip-shaped area of liquefaction at the surface, which by evaporation of the fluid leaves a bubble-like depression, while in some growths but little or no liquefaction occurs along the needle puncture. Other vibrios besides the cholera germ, however, produce this same type of liquefaction; and the cholera spirillum itself sometimes liquefies tube cultures in a different manner.

On agar plates the colonies may be readily distinguished from those of B. coli by their thin, transparent appearance. This feature is frequently of importance in effecting a speedy diagnosis by means of plates made directly from feces.

Blood-serum is rapidly liquefied. On potato at 37° C. a viscid brownish growth is produced. In broth growth is luxuriant; the medium becomes rapidly clouded, and a wrinkled pellicle is formed at the top. In milk growth takes place without producing any visible change. When the cholera spirillum is grown in peptone broth containing a small amount of nitrate,* the nitrate is reduced to nitrite, and at the same time indol is produced. The addition of a few drops of concentrated sulfuric acid to the culture then gives rise to a red color—the cholera-red reaction. This was at one time supposed to be distinctive of the cholera spirillum, but is now known to be given by a number of other vibrios, so that as a positive test it is not diagnostic. Its absence, however, is possibly of some importance in the identification of the cholera germ, provided nitrite is known to be present at the time the test is made. The reaction itself is none other than the familiar nitroso-indol reaction, and is given by any organism (*e. g.*, the colon bacillus) that forms indol and reduces nitrate.

The cholera spirillum is a strongly aërobic organism and refuses to grow under a strip of mica laid over a gelatin plate; in fluid cultures the vibrios collect at the surface. An alkaline reaction of the culture-medium is also essential to its development, a small quantity of acid being sufficient to prevent growth altogether.

The resistance of the cholera vibrio to various injurious influences is not great. It is killed by moderately high temperatures very readily (ten minutes at 60° C.), is destroyed quickly by the chemical disinfectants, and does not retain its vitality long in association with the ordinary saprophytic bacteria of the soil or water. Toward desiccation it is especially sensitive; if a drop of broth culture be dried on a cover-slip, the vibrios are all dead in about two hours. The facts which attest the slight resistance of the cholera spirillum, especially its sensitiveness to drying, explain the rapid and complete disappearance of cholera in once infected localities, and also the circumstance that the disease is rarely, if ever, transmitted by aërial infection. Whether or not the cholera vibrio is able to multiply outside the body in impure water is in doubt. In some peaty river-waters at least, as shown by Hankin for the Ganges and Jumna

* This may be present as an impurity in the table-salt or some other ingredient used in making the nutrient broth, or may be specially added.

rivers, the conditions for multiplication, and even for the continued vitality of the organism, are highly unfavorable. Upon the surface of vegetables and fruits kept in a cool moist place experiments have shown that the spirillum may retain its vitality for from four to seven days.

In isolating cholera spirilla from the dejecta or intestinal contents of cholera patients or of suspected cases, it is advantageous not only to plate directly in gelatin, but also to inoculate tubes of broth or peptone solution with a drop of the material and incubate for about eight hours. Gelatin plates may then be made from a loopful taken from the surface of these tubes, and any cholera-like colonies that develop in thirty-six to forty-eight hours fished and subjected to further study. A special enrichment method is of great value in isolating the cholera spirillum from infected water: To 500 c.c. or a larger quantity of the water add a peptone-salt solution (20 per cent. peptone, 10 per cent. salt) in such proportion that the mixture shall contain 1 per cent. peptone; incubate at 37° C. for eight to twelve hours and plate from the surface.

Pathogenesis for Man.—The causal connection between Asiatic cholera and the micro-organism discovered by Koch has been demonstrated by a number of unfortunate laboratory accidents affecting persons working with pure cultures of the microbe in question. One of these cases occurred in Hamburg in September, 1894, at a time when there were no other cases of the disease in that city.* Dr. Emil Oergel, assistant in the Hamburg Hygienic Institute, became accidentally infected in the course of his laboratory work, probably by drawing into his mouth through a pipet some of the peritoneal fluid from an inoculated guinea-pig with which he was experimenting. Clinically, the patient presented a typical picture of severe cholera; a nearly pure culture of the cholera vibrio was found in the stools, and about nine days after the probable infection the case terminated fatally. In another German laboratory two experimenters, Pettenkofer and Emmerich, voluntarily partook of a small quantity of a broth culture of "Koch's vibrio," and as a result developed mild but genuine cases of Asiatic cholera. By such instances the relation between Asiatic cholera and the particular spirillum has been demonstrated with sufficient emphasis.

* Reincke: Dtsch. med. Wchschr., 1894, 20, p. 795.

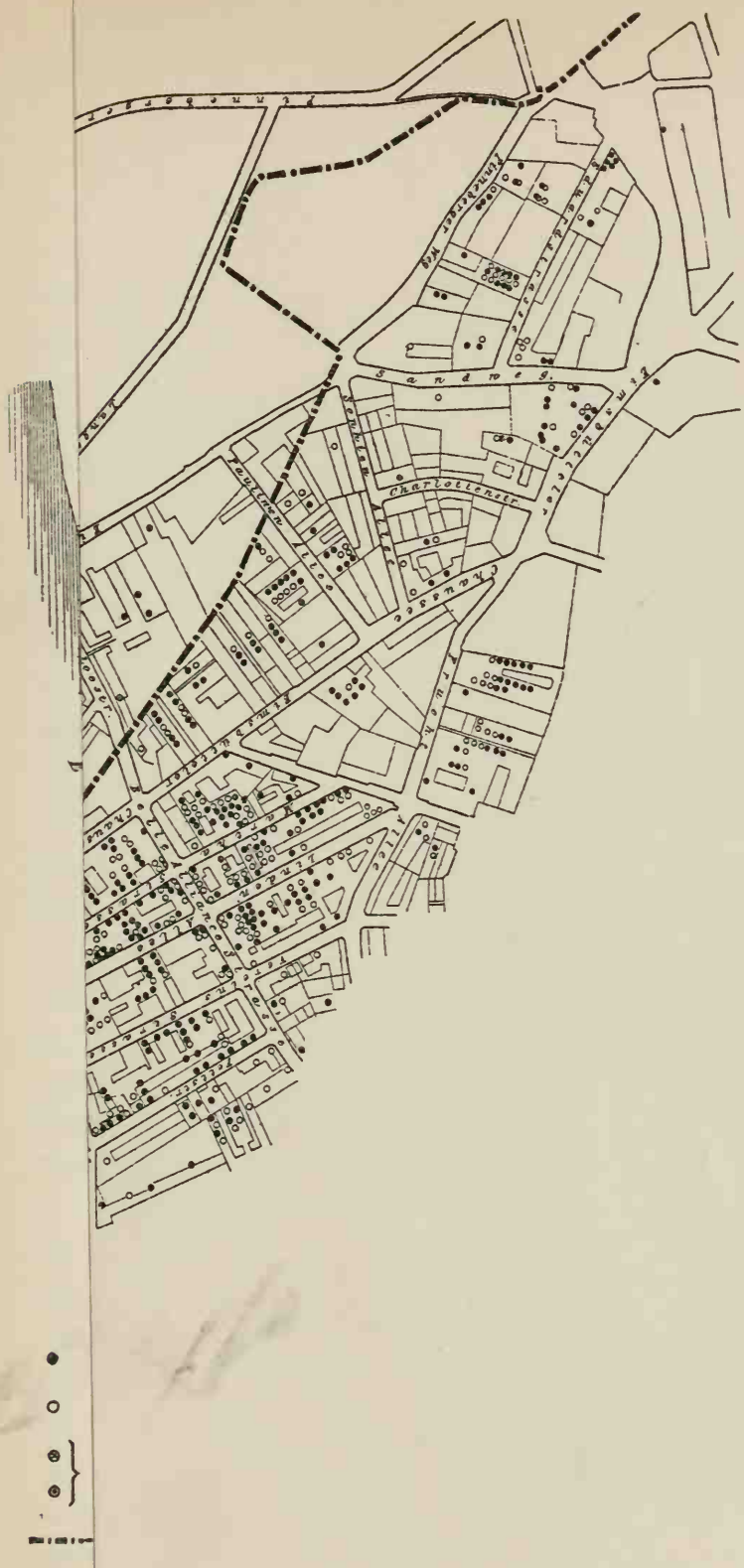
Both laboratory cases of cholera and those cases contracted naturally in the course of epidemics are marked by great differences in the susceptibility of different individuals. The reason for this probably lies partly in individual differences in natural innate resistance, partly in the fluctuations that occur in such resistance. It is well known that when cholera is prevalent, certain persons contract the disease and succumb to it more readily than others apparently equally exposed to infection. Fatigue, the excessive use of alcohol, and various factors leading to mild, non-specific gastro-intestinal derangements, predispose in a marked degree to attacks of cholera.

The tissue changes observed at autopsy are not characteristic. Kidneys and liver frequently show cloudy swelling, but this is not invariable. The intestinal tract, especially the lower half, is sometimes congested, sometimes affected with extensive necrosis and formation of a false membrane; the latter condition is seen particularly in the more chronic cases.

The cholera spirilla usually occur in immense numbers in the contents of the intestines, but do not invade the blood, and are not found in the internal organs. They penetrate to some extent, however, into the wall of the intestine itself, and loosen by their action the epithelial cells, which are shed into the intestine, giving the characteristic "rice-water" appearance to the stools and intestinal contents. In the rice-water stools the spirilla are often found in pure culture, but in later stages, and in the so-called cholera-typhoid condition, other bacteria become so abundant that the isolation of the cholera spirillum from choleraic dejecta becomes much more difficult.

Modes of Dissemination; Epidemiology.—Cholera, like typhoid fever, is spread largely by means of infected drinking-water. The short period of incubation and the rather unmistakable clinical picture often render the water-borne epidemics of cholera more easily traceable to their source than those of typhoid fever. The explosive character of such outbreaks is usually striking. In the famous "Broad Street pump" epidemic of cholera in London in 1854,* there were in the district affected twelve deaths from cholera

* Report on the Cholera Outbreak in the Parish of St. James, Westminster, during the Autumn of 1854. London, J. Churchill, 1855.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during a period of thirteen days preceding the outbreak; then in four successive days the number of deaths leaped to three hundred and forty-four. A similar explosive outbreak occurred on August 20, 1892, in Hamburg, when the water-supply of that city became infected (Fig. 106). The epidemic at Hamburg affords particularly strong evidence of the relation between drinking-water and cholera, as shown by the following facts. The neighboring city of Altona, which is separated from Hamburg only by a political not by a social or topographic boundary-line, derives its water-supply from the river Elbe, purifying it by sand-filters. The supply of Hamburg in 1892 came from the same stream, but at that time was not filtered. Throughout the period when Hamburg suffered severely from cholera Altona remained practically exempt. Houses on one side of a street which were supplied with water from the Hamburg mains developed many cases of cholera, while those on the other side, although under identical social and climatic conditions, built on the same soil, and provided with the same sewerage system, but supplied with Altona water, remained free.*

Milk and other articles of food ordinarily consumed in an uncooked state may likewise be the vehicle by which the cholera germ is conveyed into the alimentary tract. Cases of cholera due to contact infection sometimes occur, those persons in the immediate household of cholera patients, and especially those concerned in the care of the latter, being always more or less liable to become infected.

The explanation of the epidemiologic relations of cholera is found in the bacteriologic observations: (1) That cholera spirilla leave the body of the patient in the feces (but not in the urine); (2) that not only patients and convalescents from cholera, but also healthy individuals from cholera-infected regions, may pass cholera spirilla in their bowel discharges.† These facts make it clear why sewage-polluted water is often the cause of outbreaks of cholera, why the soiling of hands, garments, bed-clothing, etc., can lead to contact infection, and why cholera can suddenly arise at a point remote from other centers of infection as a consequence of the arrival of

* Koch: Ztschr. f. Hyg., 1893, 14, p. 393.

† Dunbar, in the Hamburg epidemic of 1892–93, found the cholera vibrio in twenty-eight persons who were entirely healthy and had never shown the slightest symptoms of cholera.

travelers from a cholera-ridden district. There is no mysterious influence of "locality" in cholera epidemics other than that the germ is introduced into certain places and not into others, and that, when once introduced, its wide dissemination is favored by certain factors, such as a polluted public water-supply, defective disposal of excremental refuse, or the unsanitary conditions that are fostered by overcrowded dwellings and extreme poverty.

So far as known, infection occurs only through the alimentary tract; the germ must be swallowed. The danger of dissemination by dust is slight, owing to the feeble resistance shown by the germ to drying. On the other hand, infection of exposed food through the agency of flies is a well-grounded probability.

Animal Inoculation.—Under natural conditions domestic animals and the animals used in laboratory experimentation never contract cholera. Somewhat heroic methods, such as alkalinization of the stomach contents with soda and slackening of the peristaltic movement of the intestine with opium, were employed by the earlier experimenters in their attempts to produce infection, and in some cases (guinea-pigs, Nicati and Rietsch*) these apparently succeeded. It was subsequently shown, however, that the choleraic symptoms and fatal termination produced in this way were also brought about by other vibrios, and were not a peculiar manifestation of the true cholera spirillum.

Experiments with rabbits have given the most important results. Injection of a very small quantity of a culture of cholera vibrios into the ear-vein results in the death of these animals with intestinal lesions not unlike those observed in man. Young rabbits may be infected through the mouth in a large proportion of cases by the simple expedient of placing cholera spirilla on the teats of the mother (Metchnikoff). Animals so infected present the characteristic features of typical cholera.

Intraperitoneal injection of guinea-pigs, while it does not reproduce typical Asiatic cholera, gives rise to a fatal infection which has been exhaustively studied by R. Pfeiffer† and other workers. The virulence of cholera cultures is frequently tested in this way, and a number of important discoveries relating to the mechanism of im-

* Nicati and Rietsch: Deut. med. Wchnschr., 1884, 10, p. 634.

† Pfeiffer, R.: Ztschr. f. Hyg., 1894, 18, p. 1; 1895, 20, p. 198.

munization and the presence of bactericidal substances in the serum have been made in connection with the study of "intraperitoneal cholera."

Toxins.—For a long time no poisonous substances akin to those contained in the broth cultures of the diphtheria and tetanus bacilli were detected in cultures of the cholera spirillum. Pfeiffer, who was one of the first workers in this field, found that young cultures in fluid media were practically devoid of toxicity. On the other hand, young agar cultures freshly killed with chloroform vapor or by heating to 56° C. were found to contain labile toxic substances. On such grounds it was inferred that the cholera spirillum produces no true toxin, but contains an endotoxin or poisonous body closely bound to the cell substance.

Metchnikoff, Roux, and Taurelli-Salimbeni,* however, found that if cholera spirilla were placed in collodion sacs in the peritoneal cavity of guinea-pigs, multiplication of the bacteria occurred within the sac and the animals died without the advent of any spirilla in the organs, blood, or peritoneal exudate. This they attribute to the production by the living cholera spirilla of a soluble toxin which diffuses through the wall of the collodion sac. Brau and Denier† and Kraus and Russ‡ have obtained yet more decisive results, and have demonstrated the presence of a true toxin in broth cultures. The serum of actively immunized animals neutralizes the cholera toxin, and hence presumably contains a true antitoxin. In animal experiments the cholera antitoxin exerts a curative effect.

Vaccination Against Cholera.—It is possible to immunize guinea-pigs and other animals by incorporating in their bodies, subcutaneously or intraperitoneally, living cholera bacteria, either of full virulence or attenuated. Bacteria killed by a moderately high temperature or by chloroform may also be used. Filtered germ-free cultures of S. choleræ, unlike those of B. diphtheriæ, possess no immunizing power. From this it is inferred that the immunity-stimulating substance, which is usually identified with the specific toxin, is closely bound to the cell body. Whatever method is em-

* Metchnikoff, Roux, and Taurelli-Salimbeni: Ann. de l'Inst. Pasteur, 1893, 7, pp. 403, 562; 1894, 8, pp. 257, 529.

† Brau and Denier: Ann. de l'Inst. Pasteur, 1906, 20, p. 578.

‡ Kraus and Russ: Centralbl. f. Bakt., 1907, Abt. I, Orig., 45, p. 258.

ployed, whether injection of living spirilla or injection of those killed by chloroform or heat (fifteen minutes at 65° C.), it is important to graduate the dose, increasing by small amounts the quantity injected. A method commonly employed in animal experimentation is to make first several injections of killed spirilla, and then, when a certain degree of immunity has been obtained, to inject living virulent spirilla at suitable intervals (*e. g.*, seven days) in gradually increasing doses. By this means a considerable degree of immunity may be produced; for example, a goat's serum, 0.02 to 0.05 c.c. of which, before treatment, is needed to protect against 2 mg. of an eighteen-hour agar culture of S. choleræ, becomes able, after the goat is immunized, to protect against the same amount of culture when only 0.001, or even 0.0001, c.c. of serum is used.

The immunity so conferred is not accompanied by the development of any antitoxic quality in the blood of the immunized animal. This is shown by the fact, among others, that an animal immunized to a high degree against living cultures succumbs just about as readily as a normal animal to inoculation with dead cultures. The active power of the immune serum depends upon its ability, when injected along with cholera spirilla into the peritoneal cavity of a guinea-pig, to cause the death and disintegration of the spirilla. Cholera immune serum is bacteriolytic, not antitoxic. The serum of an immunized animal (goat, Pfeiffer) may be so potent that 0.0001 c. c. is sufficient to protect a guinea-pig against intraperitoneal injection with ten times the minimum fatal dose of cholera spirilla. The bactericidal property of the immune serum is specific: anti-cholera serum will not destroy S. metchnikovii or other vibrios related to but not identical with the true cholera spirillum.

While the serum produced in this way possesses considerable preventive, it has little or no curative, power. If within one-half hour after intraperitoneal injection with a loop of a virulent cholera culture a guinea-pig is injected with anti-cholera serum of high potency, the life of the animal is saved; if, however, a period of one and one-half hours be allowed to elapse, large doses of serum are of no avail. In the latter case, indeed, the spirilla are destroyed, but the time interval has given such an opportunity for multiplication that the amount of poisonous substance liberated from the bodies of the dissolved bacteria is enough to cause death. After

a still further interval the bacteriolytic action is much lessened, and finally is no longer manifest.

The results obtained in man with the serum of immunized animals are in general accord with the outcome of animal experimentation as above related. The principle of passive immunization, which is so effective in the case of diphtheria, has not as yet come into general use in cholera, although the work of Kraus and Russ indicates the applicability of the method, and the possibility of its future extension.

Active immunization of human beings has, on the contrary, been advocated and rather extensively practised. Passing over the work of Ferran (1884) as of little practical importance on account of his use of impure cultures and of other loose methods of experimentation, the first really noteworthy venture in this direction is the work of Haffkine.* This experimenter used first a weak virus, that is to say, a culture attenuated by long cultivation or by growth at a high temperature (39° C.), and then followed this five days later with a virulent culture, both inoculations being made subcutaneously. Haffkine's main field of application of his method has been that home of cholera, British India, where many thousands of Europeans and natives have been vaccinated. The success of this treatment as a prophylactic method is attested by a large body of statistics which, while leaving something to be desired on the score of comparability and accuracy, nevertheless carry conviction on the main point. The following illustration of the incidence of cholera upon the two groups of vaccinated and unvaccinated in a certain part of India will show the nature of the evidence (Powell†).

	Number	Cases	Deaths
Unvaccinated	6549	198	124
Vaccinated	5778	27	14

More recently a similar method of vaccination has been devised by Kolle,‡ which consists in inoculation with cultures killed by heating to 58° C. for an hour. The efficacy of this method has been tested to some extent by examination of the bacteriolytic power of the serum of vaccinated persons. Kolle's method has also been

* Haffkine: Brit. Med. Jour., 1895, 2, p. 1541.

† Powell: Jour. Trop. Med., 1899, 2.

‡ Kolle: Deut. med. Wchnschr., 1897, 23, p. 4.

extensively used in an epidemic of cholera in Japan, where the results were, if anything, somewhat more favorable than the results obtained in India.*

The mode of action of cholera-immune serum upon the cholera vibrios has been thoroughly studied by Pfeiffer,† Ehrlich, and others. When brought in contact with the serum, the bacteria successively lose their motility, become swollen and paler, and break up into rounded, coccus-like granules which finally dissolve and disappear altogether. These changes are observed not only in spirilla introduced into the peritoneum of an immunized guinea-pig, but also in spirilla mixed with fresh immune serum outside of the body. The test-tube experiments have afforded a means of studying the mechanism of bacteriolysis. Two substances have been shown by Ehrlich to be concerned in the lytic process. One of these, the complement, is a labile substance contained in abundance in the serum of normal animals; the other, the amboceptor, a more stable body, is developed in the organism during the process of immunization, although there is evidence that small amounts of amboceptor occur in the normal animal. Neither substance alone can destroy the cholera vibrio. The relation of these two substances is shown by the following table, further details concerning the action of the cholera and other bactericidal sera being given in the chapter on Immunity (pp. 141–146).

Normal serum (Complement + small amount of Amboceptor)	Slight bacteriolysis.
Immune serum (Complement + Amboceptor)	Bacteriolysis.
Heated immune serum (Amboceptor only, Complement destroyed)	No bacteriolysis.
Heated immune serum plus normal serum (Amboceptor + Complement)	Bacteriolysis.

Allied Varieties.—A number of vibrios more or less closely resembling the cholera spirillum have been found in the stools of persons suffering from cholera, in sewage, and in polluted water. Some of these exhibit slight differences in size, number of flagella, ability to reduce nitrate, to produce phosphorescence, etc., and have been given names such as S. Ghinda, S. Massowah, S. Danu-

* Murata: Centralbl. f. Bakt., Orig., 1903–04, 35, p. 605.

† Pfeiffer: Ztschr. f. Hyg., 1894, 18, p. 1; 1895, 20, p. 198; Sobernheim: ibid., 438.

bicus, S. phosphorescens, etc., which refer to some biologic peculiarity, or to the locality where the vibrios were found. The agglutinative and bacteriolytic tests have afforded a means for distinguishing between these allied varieties and the true cholera spirillum, and less emphasis is now laid upon other points of divergence and resemblance than was the case at an earlier period. The organism known as S. Massowah, cultivated by Pasquale from human dejecta (non-choleraic), and S. Ghinda, found in well-water, were for a long time considered as true cholera germs, but have been shown to respond negatively to the serum test. It must still be regarded as an open question how far these cholera-like vibrios found in persons suffering from cholera or a cholera-like disease are responsible for the symptoms with which they are associated. From analogy with the typhoid group of diseases, as well as for other reasons, it seems probable that very similar, if not practically identical, symptoms and lesions may be produced by micro-organisms differing in agglutinative and bacteriolytic affinities. The majority of the cholera-like vibrios, so far as studied, however, are probably essentially saprophytic forms, or, at most, possessed of slight pathogenic power.

The Spirilla of Relapsing Fever

In 1873 Obermeier* announced the discovery of a large spirillum in the blood of patients suffering from a peculiar disease known as relapsing fever, which has been known since the early part of the eighteenth century, and has at times prevailed extensively in parts of Europe. The characteristic feature of this affection is that after apparent recovery and the cessation of all active symptoms one or more relapses invariably follow. A similar malady is common in India at the present time. Relapsing fever occurs occasionally in widely separated parts of the world, although apparently tending to become less frequent. In recent years few cases have been observed in the United States.† The European variety of the disease is not a very fatal one, the case-mortality being stated by Murchison‡ to be about 4 per cent.

* Obermeier: Centralbl. f. d. med. Wissensch., 1873, 11, p. 145.

† For a careful report of two cases see Carlisle, Jour. Infect. Dis., 1906, 3, p. 233.

‡ Murchison: "A Treatise on the Continued Fevers of Great Britain," London, 1873.

Chief Characteristics.—S. obermeieri (S. recurrentis) is a tapering, spiral filament, varying in length from one and one-half times (probably the young single cell) to ten times the diameter of a red blood-corpuscle (agglutinated cells). The breadth of the cell is about 0.39 μ. The number of turns in the short spirilla or individual cells is usually but two or three, but may increase to eight to ten prior to division. The individual spirals have a single flagellum at one end, and display a very active screw motion, with some

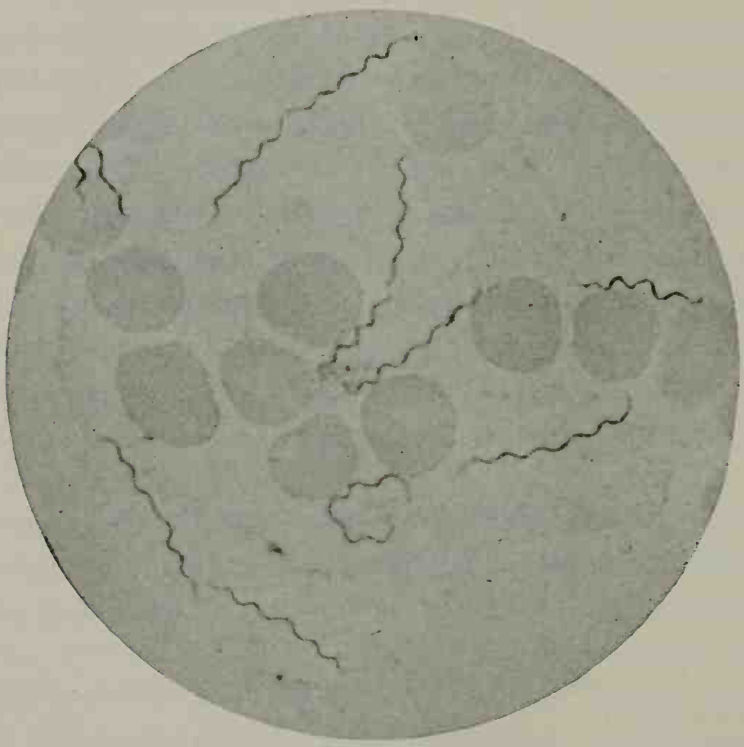

Fig. 105.—Spirillum obermeieri in blood of rat, showing divisional forms. A group showing spirilla of different lengths. The two long ones above show transverse division; × 1500 (Novy and Knapp).

lateral oscillation and, under favorable conditions, rapid forward-backward excursions (Fig. 105 and 107). The contents of the cell usually stain uniformly by the Romanowsky method, with the exception of the ends, which are pale and fade away to a point (Novy). Attempts at cultivation on artificial media have not succeeded, but, according to Norris, Pappenheimer and Flournoy,* multiplication takes place in rat's blood prevented from coagulating by sodium citrate. Novy, however, could not confirm this observation

* Norris, Pappenheimer and Flournoy: Jour. Infect. Dis., 1906, 3, p. 266.

Relationship and Nomenclature.—Schaudinn* was first to assert that the special organism seen in relapsing fever belonged, not to the bacteria, but to the protozoa, basing this opinion on its alleged possession, like trypanosomes, of a definite nucleus, blepharoblast, undulating membrane, and flagellum. Novy and Knapp,† however, have shown that this view is incorrect: no nucleus, blepharoblast, or undulating membrane could be demonstrated by these observers. The flagellum is like that of bacteria in general and is not of the protozoan type; multiplication takes place by transverse, not longitudinal, division, and is very rapid; toward plasmolytic agents and toward heat S. obermeieri behaves like bacteria, not protozoa; active immunity of a high degree is readily established. In view of these facts there seems no doubt that this micro-organism should be classed with the true bacteria.‡

Fig. 107.—Spirillum obermeieri in blood of rat. Shows a long free flagellum at one end and a rudimentary one at the other. Löffler's stain. Note that the flagellum seems to be given off from the side of the tip; × 3000 (Novy and Knapp).

Pathogenesis.—The spirilla of relapsing fever can be transmitted by inoculation to man, monkeys, mice, and rats. Carlisle§ describes a case in man occurring as the result of accidental inoculation, probably from the bite of a monkey in the course of experimental work with the spirillum. A typical paroxysm, with severe frontal

* Schaudinn: Arb. a. d. kais. Gesundh., 1904, 20, p. 387.

† Novy and Knapp: Jour. Infect. Dis., 1906, 3, p. 291.

‡ "Spirochete" is sometimes used as the generic name for this and similar long spiral forms, but the flexibility of the cell on which this generic distinction is founded is manifest to some extent in the cholera germ and other vibrios; this character hardly affords an adequate basis for group differentiation. The term spirochete is, however, often applied to the spirilla of the relapsing fevers even by those who are unwilling to regard them as a separate genus.

§ Carlisle: Jour. Infect. Dis., 1906, 3, p. 233.

headache, sharp pains in the back, and fever, was followed by a critical defervescence, ending apparently in complete recovery. In about a week a second paroxysm occurred, and then, after a remission, a third. This is fairly typical of the course of cases of relapsing fever observed in an epidemic. Sometimes four or even more relapses occur. The spirochetes are found in the blood during the febrile paroxysm, but tend to diminish in number during succeeding relapses.

Certain monkeys may be infected by subcutaneous inoculation with human or animal blood containing spirochetes. The infection in these animals, like the naturally contracted relapsing fever in man, is characterized by successive attacks of illness, usually three or four in number, accompanied by the appearance of spirochetes in the peripheral blood. The rise in temperature at the time of the paroxysm is less marked and less constant in monkeys than in cases of human relapsing fever. The course of the disease is usually benign, the inoculated animals speedily regaining their health after the last paroxysm.

White mice are very susceptible to inoculation, and typical relapses occur in these animals. White rats also are readily infected, and spirilla are found in large numbers in the blood, but relapses have never been observed.

The pathologic anatomy of the disease presents nothing very characteristic. The spleen is generally enlarged.

Immunity.—Novy and Knapp have carried out some important studies on immunity, which not only explain the crisis and the relapse, but establish a basis for the cure and prevention of relapsing fever and related affections. In blood drawn before the onset of an attack, spirilla will remain in a living motile condition as long as forty days, whereas in blood drawn during the decline of the attack, or after recovery, they have been observed to die out within an hour. In the latter case a powerful specific germicidal body is present. When the spirilla are killed or weakened by the germicidal agent, they are taken up by the phagocytes. It usually happens that some of the spirilla escape this fate, and after an interval become able to multiply, perhaps because of the partial disappearance of the antibodies, perhaps because the spirilla themselves become immune

to the antibodies.* Novy and Knapp believe that besides the germicidal agent, an immunizing agent is present, and that the relative amount of these two substances at the close of an attack determines whether or not a relapse will occur. Active immunity follows recovery from infection, and a condition of hyperimmunity can readily be established in rats by repeated injections of blood containing spirilla. The blood of recovered or immunized animals can be used to produce passive immunity, and preventive inoculation can be successfully practised in rats, mice, and monkeys. Animals already infected can be cured, and subsequent relapse prevented by curative doses of blood (about five immunity units per gross body-weight, Novy).

There are probably at least five distinct diseases caused by organisms similar to the spirillum of European relapsing fever. A disease of man, proved to be transmitted by the bite of a tick, and known as tick fever,† is widely prevalent in equatorial Africa, and has been shown to be due to a spirillum. The spirillum of West African tick fever (S. duttoni) differs from S. obermeieri in being about twice as long as the latter, in having wider or looser turns to the spiral, and in possessing diffuse flagella. Fewer spirilla are found in the blood of man in tick fever than in relapsing fever, and the effects produced in monkeys and rats by inoculation with S. duttoni are quite different from those caused by S. obermeieri. Another form of African tick fever (East African) is due to a third variety of spirilla, S. kochi.

The spirillum found in a kind of relapsing fever observed in Bombay, India, is apparently different from both of the foregoing (Novy). A number of investigators regard the American case of relapsing fever studied by Novy and Knapp as due to still a fifth spirochete

* "Hitherto it was believed that the relapse was due to the survival, in extravascular spaces, of spirochetes which, after the partial destruction or elimination of the specific antibodies, were able again to invade the circulation. In the light of the facts now known it is clear that the relapse is due to the survival of a few individuals which have acquired more or less immunity to the specific germicidal bodies elaborated in the infected animal. As a result a new 'serum-fast' strain develops, which in turn calls for a new antibody. The latter is apparently not as active as the first, or is more unstable, or is more readily eliminated, and hence the continuance of the relapses with this organism." (Novy: Science, 1908, 27, p. 650.)

† Dutton and Todd: Brit. Med. Jour., 1905, 2, p. 1259.

(S. novyi), and Schellack* has given exact details of the morphology of the African, American, and European (Russian) forms. Among other organisms of this clan may be mentioned S. anserinum, causing a disease of geese,† S. gallinarum, connected with a very fatal disease of chickens conveyed by tick-bite;‡ and S. theileri, found in small numbers in a benign affection of cattle in South Africa.§ Spirilla have also been found in the blood of sheep, horses, and bats.

Other Pathogenic Spirilla

S. metchnikovii.—The organism known by this name was first discovered by Gamaléia‖ in the intestinal tract and blood of fowls suffering from an epidemic disease resembling fowl cholera. It is extraordinarily like the cholera spirillum in all its morphologic and cultural characters, practically the only difference observed being in the colonies on gelatin plates, which, in the case of S. metchnikovii, sometimes have a brownish tinge, show turbidity of the liquefied gelatin, or diverge in other slight particulars.

Fig. 108.—Spirillum metchnikovii in exudate from pigeon. × 1000 (Günther).

Inoculation of pigeons affords a ready means of distinguishing this organism from S. choleræ. Pigeons are unaffected by injection of relatively large numbers of the latter bacterium, but usually succumb within twenty-four hours to septicemia when pricked with a needle dipped in a culture of S. metchnikovii (Fig. 108). For guinea-pigs also the pathogenicity of S. metchnikovii is higher than that of the cholera vibrio. These animals, on subcuta-

* Schellack: Arb. a. d. kais. Gesundh., 1907, 27, p. 364.

† Sacharoff: Ann. de l'Inst. Past., 1891, 5, p. 564.

‡ Marchoux and Salimbeni: Ann. de l'Inst. Past., 1903, 17, p. 569.

§ Jour. of Comp. Path. and Therap., 1903, 47, p. 55.

‖ Gamaléia: Ann. de l'Inst. Past., 1888, 2, p. 482.

neous inoculation, fall victims to a rapidly fatal septicemia; if the stomach contents are rendered alkaline, infection can also be produced by feeding.

Further evidence of the difference between these forms is given by the agglutinative reaction and Pfeiffer's serum test. The serum of an animal immunized against intraperitoneal cholera will not protect against S. metchnikovii, and will not agglutinate it. The reciprocal statement is also true. Vibrios similar to, and perhaps fully identical with, S. metchnikovii have been isolated by several observers from polluted water. "Vibrio Massowah," an organism long maintained in laboratory collections under the impression that it was a strain of the true cholera spirillum, is now regarded as more closely related to S. metchnikovii.

The "spirillum of Finkler and Prior" was originally discovered in old stools obtained from a case of cholera nostras.* It does not give the typical cholera-red reaction, and may be differentiated in other ways from the cholera spirillum. At present the microbe has only a rather remote historical interest, and would hardly need to be mentioned save for the fact that it has long been cultivated in bacteriologic laboratories, and consequently used to some extent in comparative and experimental work. The same may be said of "Deneke's spirillum," the so-called S. tyrogenum. The latter organism has very feeble pathogenic power for laboratory animals; the spirillum of Finkler and Prior usually displays more, but never a high, virulence.

A phosphorescent vibrio (S. phosphorescens) isolated from river-water in parts of Germany possesses a decided resemblance to the cholera spirillum, but besides giving luminous cultures, is not influenced by specific cholera serum.

The Micro-organism of Syphilis—Treponema Pallidum

Syphilis is essentially an infectious disease, acquired by sexual congress or transmitted by a diseased parent. There are, however, many other modes of infection. Physicians are not infrequently inoculated in the course of surgical and obstetric practice; wet-nurses of syphilitic children are sometimes infected; and there have been rare cases in which syphilis was communicated by vaccine

* Deut. med. Wchnschr., 1884, 10, p. 632.

lymph of human origin. The disease is often congenital, and either parent may be responsible for hereditary transmission.

At various times certain micro-organisms have been thought to be causally connected with syphilis, but the evidence for such connection has, until recently, not been very convincing. Lustgarten* in 1884 described a bacterium resembling the tubercle bacillus which he found in the primary sore of syphilis and in the lesions in internal organs. Although Lustgarten's bacillus was subsequently found in syphilitic lesions by many observers, its similarity to the smegma bacillus, together with other considerations, prevented its general acceptance as the cause of syphilis. At the present time the micro-organism that has the best claim to be considered the causal agent of syphilis is a spirillum-like form known as Treponema pallidum.†

Attention was first directed to this organism by Schaudinn and Hoffmann,‡ and their results were speedily confirmed and extended by Metchnikoff and others. The chief reason why this organism had not been previously discovered by the numerous students of syphilitic lesions seems to be that the spirillum is very difficult to see unstained in the fresh state, and is also exceedingly refractory to stains. The method of staining cover-slip smears found most successful by Schaudinn and Hoffmann consists in the use of Giemsa's eosin solution and azur.

12 parts Giemsa's eosin solution (2.5 c.c. of 1 per cent. eosin; 500 c.c. water).
3 parts azur No. I. (1 : 1000 solution in water).
3 parts azur No. II. (0.8 : 1000 solution in water).

The staining mixture should be freshly prepared. Thin films are dried in the air, hardened in absolute alcohol, and immersed in the stain for sixteen to twenty-four hours. They are then washed in water, dried in the air, and examined in cedar oil. By this method the spirilla are stained a pale rose color.

The silver precipitation method, familiar in neurologic work, has been found particularly serviceable for staining the spirochete in

* Wien. med. Wchnschr., 1884, 34, p. 1389.

† *Spirochæta pallida* was the name first bestowed, but was found to have been applied, long before, by Ehrenberg to another organism.

‡ Schaudinn and Hoffmann: Arb. a. d. kais. Gesundh., 1905, 22, p. 527; Deutsch. med. Wchnschr., 1905, 31, p. 711.

tissues, and by its aid the presence of spirochetes in great abundance in congenital syphilis has been demonstrated. Levaditi and Manouélian recommend the following procedure:*

1. Fixation of fragments of organs (1 to 2 mm. thick) for twenty-four to forty hours in 10 per cent. formalin.

2. Washing with 96 per cent. alcohol twelve to sixteen hours.

3. Washing with distilled water until fragments no longer float.

4. Impregnation two to three hours at room temperature and four to six hours at about 50° C. in the following bath: Silver nitrate solution, 1 per cent.; pyridin solution (added 10 parts per 100 at moment of use).

5. Very rapid washing in a 10 per cent. pyridin solution.

6. Reduction by the following bath: Pyrogallic acid, 4 per cent.; 10 parts per 100 purified acetone, $\frac{5}{5}\frac{6}{8}$, and 15 parts (per total vol.) of pyridin (added at moment of use). The reduction occurs in a few hours.

7. The usual alcohol series; xylol; paraffin; section. The sections may be stained with Unna's blue.

In size the spirilla usually range from 4 μ to 20 μ in length and are very slender, probably rarely reaching 0.5 μ in thickness. The turns in the spiral are close and regular; the number of curves ranges from three to twelve and may reach as high as forty (Goldhorn†). There is a fine flagellum at each pole (see Fig. 109). Movement forward and backward may occur, and also rotation on the axis. The cell is not a perfectly rigid spiral, but is quite flexible. It is not yet definitely settled whether division is transverse or longitudinal. If longitudinal, Treponema should perhaps be ranked as one of the protozoa, possibly related to the Trypanosomes, though it must be said that some writers do not regard the mode of division as a decisive criterion. Treponema, like the spirochetæ in general, has, so far as known, no complicated life history with a succession of different forms, and in this respect resembles the bacteria. At present the systematic position of this organism may be regarded as unsettled, although the majority of investigators incline to place it with the true bacteria or, at best, in a group midway between the bacteria and protozoa. Attempts at cultivation on artificial media have never yet been successful.

* Levaditi and Manouélian: Comp. Rend. Soc. de Biol., 1906, 60, p. 134.

† Goldhorn: Jour. Exper. Med., 1906, 8, p. 451.

What is the evidence that Treponema pallidum is the cause of syphilis? In the first place, this micro-organism, which is well defined and distinguishable from all other known spirochetes, can be found almost uniformly in the primary lesion or hard chancre. The germ is sometimes localized in the sore in such a way that its presence is not discovered by simple cursory examination, but a thorough search usually reveals it. In the skin eruptions of the so-called secondary stage, Treponema is also present, being often demonstrable in great abundance in the papules. The mucous lesions of this stage likewise contain the spirillum, a fact that serves to explain the observed virulence of the saliva. The spirilla have been found also in the internal organs, such as the liver, kidney, and spleen. Several observers have reported finding Treponema in the circulating blood, although its presence in this situation is naturally difficult to demonstrate. In the tertiary stage the organisms were found at first infrequently, but later observers have been more successful, and there is no doubt that the spirochetes are present in the tertiary lesions also, although in greatly reduced numbers. A number of observers (Finger and Landsteiner,* Neisser†) have proved that material from tertiary lesions can produce infection, although many of the attempts result in failure.

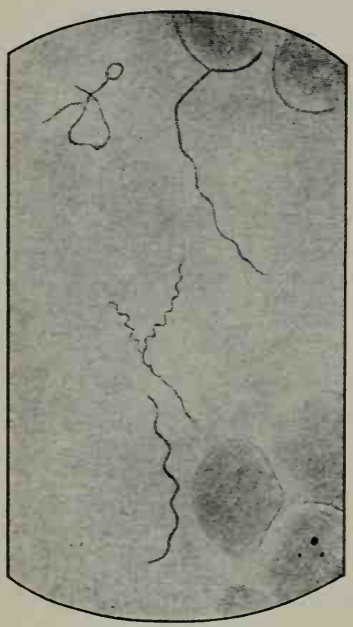

Fig. 109.—The two spirochetes in the center are *Treponema pallidum*, the three others, *Spirochæta refringens* (Schaudinn and Hoffmann).

Important testimony in favor of causal relationship is afforded by the presence of Treponema pallidum in the lesions of congenital syphilis (Fig. 110). The microbe is found in large numbers and in pure culture in the internal organs of syphilitic infants and under conditions where secondary infection would seem to be excluded. In the liver especially the spirilla are very abundant. The organism seems to be primarily an

* Finger and Landsteiner: Sitz.-Ber. Akad. Wiss., 1905, 1906.

† Neisser: Deut. med. Wchnschr., 1904, 30, pp. 1369, 1431; 1906, 32, pp. 1, 49, 97.

intracellular parasite, which is especially apt to attack glandular epithelium.

Still further indication of the pathogenicity of this micro-organism is given by its frequent occurrence in the syphilitic lesions of monkeys that have been successfully inoculated with syphilitic material from man or from another monkey. Metchnikoff and Roux* determined the presence of Treponema in 70 per cent. of such cases that they examined. As in the lesions of congenital syphilis, the micro-organism is found in the infected monkeys in pure culture.

The earlier attempts to inoculate the lower animals with syphilitic virus gave variable and conflicting results. Metchnikoff and Roux were the first to show that syphilis could be successfully and uniformly communicated to monkeys, and that the material from

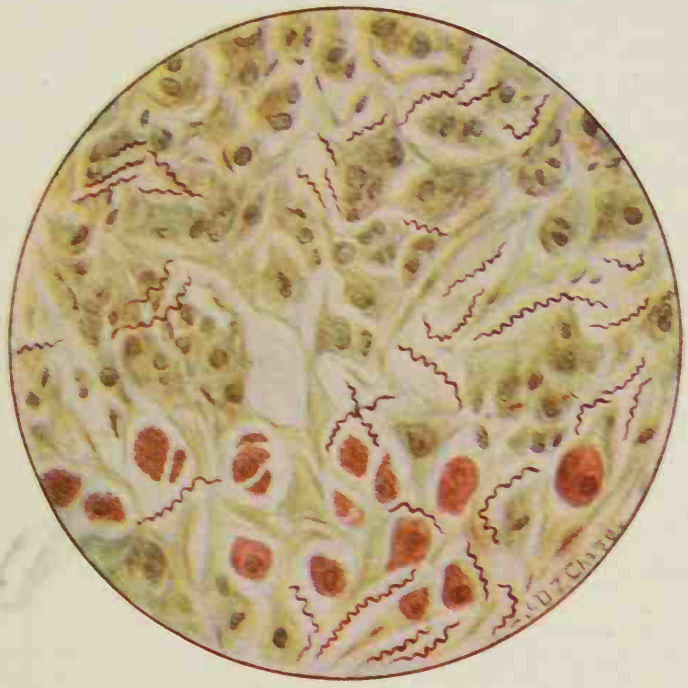

Fig. 110.—Treponema pallidum in congenital syphilis. × 1000. Levaditi (Sobernheim, in Kolle and Wassermann).

the lesions so produced could be used for successive reinoculations. The technic of inoculation is important. Subcutaneous, intraperitoneal, and intravenous inoculations, even of the most virulent material, are without effect, but cutaneous inoculation, particularly

* Metchnikoff and Roux: Ann. de l'Inst. Past., 1903, 1904, 1905.

upon the eyebrows and genitals, is usually followed by typical primary lesions. Positive results are almost invariably obtained in these situations when the virus is freshly procured and when deep scarification is practised. The period of incubation varies from fifteen to fifty days. Practically all species of monkeys are susceptible. Material from the primary and secondary lesions and from congenital syphilis has been found capable of producing infection. In the higher monkeys (chimpanzees and gibbons) the primary effects have been followed by typical secondary syphilitic manifestations after a few weeks. Spirochetes have been found in simian syphilis distributed in the same manner as in man, although in less abundance, as corresponds with the lower susceptibility of the monkey tribe.

Bertarelli,* Schucht,† and others have been able to produce inoculation syphilis of the iris and cornea in rabbits. The average period of incubation in these animals is about twenty-nine days. The process remains localized, and none of the rabbits showed lesions in the internal organs. Tre. pallidum was found in large numbers in the affected parts.

These several lines of evidence do not perhaps constitute irrefragable proof, but taken together furnish a strong basis for the belief that Treponema pallidum is the cause of syphilis. Neither the bacillus found in leprous tissues nor the trypanosomes found in the blood in sleeping sickness have yet been cultivated outside of the body and made to reproduce the disease by inoculation in pure culture, but there is little doubt in the minds of bacteriologists that the microbes associated with these diseases stand in causal relation to them. At the present writing the same seems to be true of syphilis.

Wassermann and his collaborators‡ have demonstrated by the method of complement deviation (p. 157) the presence of specific antibodies in the serum of monkeys treated with syphilitic virus. All attempts at active and passive immunization have thus far failed.

* Bertarelli: Centralbl. f. Bakt., Orig., 1906, 41, p. 320.

† Schucht: Munch. med. Wochnschr., 1907, 54, p. 110.

‡ Deut. med. Wochenschr., 1906, 32, pp. 745, 1769; Ztschr. f. Hyg., 1907, 55, p. 451.

The Wassermann reaction for the diagnosis of syphilis has been extensively used. If the inactivated serum from a suspected luetic is mixed with organ extract (luetic liver or guinea-pig heart macerated, extracted with alcohol and inactivated) and complement (fresh guinea-pig serum) added, the complement is bound if the antigen finds an homologous antibody in the serum, that is, if the serum is genuinely syphilitic. To determine whether this anchoring of the complement has taken place, the mixture, after standing for a time, is brought in contact with another mixture (of washed sheep's corpuscles and inactivated specific hemolytic serum obtained by injecting a rabbit with sheep corpuscles), which consists of red corpuscles and their specific amboceptor. Should the complement in the first mixture not be anchored, the "hemolytic system" will be complete and hemolysis will occur.*

The reaction is a complicated one and it is necessary to control it carefully. A common source of error has been the use of too large a quantity of organ extract, which has the effect of bringing about an anchoring of the complement even in the absence of the specific antibody in the serum. Noguchi† has devised a modification of the Wassermann method which is simple and exceedingly delicate.

Yaws

Castellani‡ has reported the presence of spiral bacteria in a disease occurring in several tropical countries, and known in the West Indies as yaws. The disease resembles syphilis, and by some writers has been regarded as identical with it. The spirillum, Treponema pertenuis, is long and very slender; there may be as many as twelve spirals. The Romanowsky staining method or some modification of it is said to give the best results. Vom dem Borne§ has found Tre. pertenuis in seventy-three out of seventy-six cases in which the young intact papules of the disease were examined. Material obtained from persons suffering from yaws and apparently containing Tre. pertenuis as the sole micro-organism is infectious for monkeys, and the spirillum is practically always present in the unbroken eruptive lesions and is often found in the spleen and lymph-nodes.

* A clear description of the technic of this method has been given by Butler, Jour. Amer. Med. Assoc., 1908, 51, p. 824.

† Noguchi: Jour. Exp. Med., 1909, 11, p. 392; Jour. Amer. Med. Assoc,. 1909, 53, p. 1532.

‡ Castellani: Brit. Med. Jour., 1905, 2, p. 1280.

§ Vom dem Borne: Jour. Trop. Med., 1907, 10, p. 345.

Castellani* has obtained evidence of the existence of specific yaws antibodies and antigens which are different from syphilis antibodies and antigens. Ashburn and Craig† emphasize the morphologic resemblance of Tre. pertenuis to Tre pallidum, but nevertheless conclude that Tre. pertenuis can be differentiated by inoculation experiments and that it is the cause of yaws.

* Castellani: Jour. of Hyg., 1907, 7, p. 558.

† Ashburn and Craig: Phil. Jour. of Sci., B. 1907, 2, p. 441.

CHAPTER XXVII

THE PATHOGENIC TRICHOMYCETES

The organisms included under this head are filamentous forms and possess many characters relating them to the group of true molds (Hyphomycetes) rather than to the bacteria proper (Schizomycetes). They may be said perhaps to stand in an intermediate position between the bacteria and the higher fungi. All have a more complicated cycle of development than has been observed in any of the true bacteria. On the other hand, they are distinguished from the higher fungi by the slenderness of their filaments and their more simple life-history. Among the so-called Trichomycetes themselves great confusion has prevailed both in classification and in nomenclature, and there is still far from being any universal agreement concerning the subdivisions of the group and their designations. The following table will serve to make clear the nature of several of the better marked divisions under what seem to the writer the most appropriate generic names:

Trichomycetes	Leptothrix.....	No branching.
	Cladothrix.....	"False" branching.*
	Nocardia†	True branching. Reproductive elements—spores—observed.
	Actinomyces.....	True branching. No spores observed.

Leptothrix Mycoses

A number of writers have reported cases of suppurative processes due to organisms of this class (B. Fränkel,‡ Arustamoff,§

* The terminal cell, in dividing, pushes the product of the previous division to one side. Thus there are two terminal cells lying side by side, and as each goes on dividing, the appearance of branching is seen.

† Sometimes termed Streptothrix, a name also applied by some writers to the whole group of Trichomycetes. According to the rules of botanic nomenclature, however, since the name streptothrix was preëmpted in 1839 for a mold belonging to the Dematiaceæ, it is not applicable to any of the organisms under consideration.

‡ Fränkel, B.: Eulenburg's Realencyklopädie der gesammten Heilkunde, 1882.

§ Arustamoff: "Zur Morphologie und Biologie der Leptothrix," Wratsch, 1889.

von Arx*). The lesions are quite commonly situated in the neighborhood of the mouth and throat. Arustamoff is the only one who has succeeded in obtaining growths of the organisms observed, and it is quite uncertain whether different species are concerned in these attacks. Some investigators have supposed that a common saprophytic inhabitant of the mouth (Leptothrix buccalis) acquires pathogenic properties under certain conditions and becomes able to invade the tissues, but in view of the inadequate recognition marks for members of this group this must be regarded as altogether problematic.

Cladothrix and Nocardia Mycoses

The descriptions given in the literature do not permit a satisfactory separation of the cases due respectively to the Cladothrix and the Nocardia forms, since the distinction between "true" and "false" branching has not been sufficiently regarded and recorded by all observers. Organisms related to one or the other of these groups have been found in a variety of situations: in the lachrymal canal, in a farcy-like disease of cattle (Nocard, "farcies du bœuf," probably nocardiosis), in an abscess of the brain (Eppinger,† who called this organism "Cladothrix asteroides," believed it to show false branching), in diseases of the lungs in various parts of the world (Japan, Aoyama and Miyamoto;‡ United States, MacCallum; South Africa, Birt and Leishman§); and in a number of affections designated as "pseudotuberculosis,"‖ or sometimes, but quite incorrectly, as "pseudoactinomycosis." Most, if not all, of the forms found in association with pathologic processes belong apparently to the genus Nocardia, since they are reported as showing true branching. This genus is also widely distributed in nature, and saprophytic nocardiæ (possibly with pathogenic potentialities) have been found on grasses and grains, and in soil and water. These organisms are for the most part cultivable aërobically in the ordinary culture-media at 20° C. and at 37° C. On the surface of these media (agar, gelatin,

* von Arx: Correspondenzbl. f. Schw. Aerzte, 1889, 19, p. 161.

† Eppinger: Ziegler's Beiträge z. path. Anat., 1890, 9, p. 287.

‡ Aoyama and Miyamoto: Mitt. d. med. Fac. Japan, 1900, 4, p. 231.

§ Birt and Leishman: Jour. Hyg., 1902, 2, p. 120.

‖ Flexner: Jour. Exper. Med., 1898, 3, p. 435; Schabad: Ztschr. f. Hyg., 1904, 47, p. 41; MacCallum: Centralbl. f. Bakt., 1902, 31, orig., p. 529.

some cultures on potato) dense masses of branching filaments are formed, the growth often possessing a reddish-brown color. Especially characteristic is the fragmentation of the filaments which occurs, resulting in the appearance of chains of spherical bodies which are regarded as spores, and which serve to reproduce the species. These spores have not the high resistance of bacterial spores, and are more closely related to the spores of the higher fungi (see p. 431). The nocardiæ, unlike the actinomyces, after having been stained with fuchsin, resist decolorization with dilute acids, although not as strongly as the tubercle bacillus. Nocardiosis seems to be acquired most frequently by infection through the respiratory tract, but wound infection has been observed.

Actinomycosis

The most clearly defined and best studied affection ascribable to filamentous micro-organisms is a disease occurring chiefly in cattle, but occasionally observed in man, and in the horse, pig, sheep, dog, cat, elephant, and a few other animals. Although the disease was undoubtedly observed early in the nineteenth century, actinomycotic tumors being described by Leblanc* in 1826 under the name of osteosarcoma, it was first recognized as a specific parasitic disease by Bollinger in 1877.† At Bollinger's instigation the fungus was studied by the botanist Harz,‡ who gave it the name of actinomyces on account of the ray-like structure of its growth in the tissues. Later workers have added materially to the knowledge of actinomycosis and its parasite, among whom may be mentioned especially M. Wolff and J. Israel§ and J. H. Wright.‖ Actinomycosis is essentially a suppurative process, characterized by the formation of granulation tissue and by the presence in the pus of peculiar granules, the *Drusen* of German writers. The granular masses when examined microscopically are seen to be dense rosettes of club-shaped filaments

* Leblanc: Jour. de méd. vétérin., 1826, p. 333.

† Bollinger: Deut. Ztschr. f. Tiermed., 1877, 3, p. 334.

‡ Harz: Deut. Ztschr. f. Tiermed., Suppl., 1878, 4, p. 125.

§ Wolff and Israel: Arch. f. path. Anat., 1891, 126, p. 11.

‖ Wright, J. H.: Pub. Mass. Gen. Hosp., Boston, 1905; Jour. Med. Res., 1905, 8, p. 349.

with the definite radial arrangement which has suggested the name of ray-fungus.

Characteristics of Actinomyces.—The features of this interesting parasite may be considered as presented—(1) in the tissues, (2) in cultures.

(1) As found in the animal tissues, the largest of the colonies of the ray-fungus are visible to the naked eye as minute yellowish granules, the individual rosettes of which the granules are composed averaging perhaps 30 to 40 μ in diameter, though they may sometimes reach a much larger size (200 μ). A granule may consist of a single rosette, or, as in the case of the largest granules, may be compacted of several. Three kinds of structures make up a typical actinomyces rosette: (*a*) a central core of branching filaments irregularly disposed, but with a general radial arrangement; (*b*) at the periphery refringent, club-shaped bodies; (*c*) spherical, coccus-like bodies. The colonies may be examined in fresh unstained preparations in which the clubs may be plainly seen, or some stain like eosin may be used, which colors the sheath of the clubs. The filaments stain by Gram's method, which is consequently well adapted for treating sections of the affected tissues.

(*a*) The filaments exhibit true branching, are often curved, sometimes spirally, and are thickly interlaced in a network like the mycelium of the higher fungi. The individual threads are, for the most part, slender (about 0.5 μ in diameter), and are composed of granular protoplasm surrounded by a delicate sheath. In the older colonies fragmentation or segmentation of the cell-substance may be observed, giving the appearance of chains of cocci.

(*b*) The club-shaped bodies at the margin of the actinomyces granule are conspicuous for their high refringency and general structureless, homogeneous, appearance. They are pear-shaped swellings of the terminal ends of the filaments, and arise as a distinct transformation of the latter. In young colonies the hyaline substance of which the clubs are composed is soft and may be dissolved in water, but as the age of the colony increases, the clubs become of firmer consistency. The clubs are found especially in colonies from lesions where there is evidence that the tissue is displaying resistance to the inroads of the micro-organism; when resistance to

invasion is slight, they are absent, filaments alone being found. Clubs are, as a rule, more common in bovine than in human lesions.

Fig. 111.—Colonies of actinomyces on agar and blood-serum (Wright).

(*c*) Coccus-like bodies have been reported by a number of observers as being present in the actinomyces granules. This designation has doubtless been applied to bodies of diverse nature. The segmentation of a filament into a chain of spherical structures has been already mentioned; these bodies are then usually described as "cocci." Some of the "coccoid" bodies are perhaps real micrococci, secondary invaders of the suppurating actinomycotic lesion, and some are perhaps simply the ends of clubs that first appear in focusing a lens down upon a rosette.

(2) In cultures the essential features of the actinomyces rosette have been reproduced. The smaller colonies are rounded masses of branching and interlacing filaments. As the filaments become older they tend to break up into segments, and the largest colonies are dense, opaque masses of short filaments and rod forms. Clubs are not formed in ordinary broth (Fig. 112), but only in the presence of blood, blood-serum, or serous pleuritic fluids (Wright), where, however, their development is inconstant and

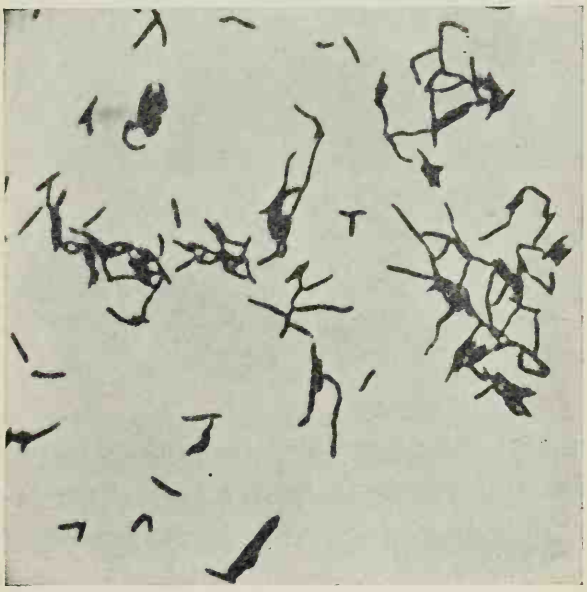

Fig. 112.—Smear preparations of actinomyces from broth culture. × 1500 (Wright).

dependent to some extent on unknown factors. Sections of the colonies stain well by Gram's method; according to Wright, the clubs are best shown in paraffin sections stained according to Mallory's method (Fig. 113).

Much discussion has centered around the biologic significance of the different elements of the actinomyces colony. The clubs were at one time supposed to be reproductive organs of some sort, but little or no evidence has been adduced in support of this view, which is now practically abandoned. As already pointed out, the clubs are formed only when the colony is in contact with animal fluids that oppose a certain degree of resistance to the growth of the organism. They are consequently thought by many to be degeneration products due to the unfavorable conditions encountered by the tips of the filaments, that is to say, to lack of space or to the restraining influence of the body-cells or body-fluids; they have also been looked upon as protective devices for resisting the destructive action of the body-fluids.

Fig. 113.—Colony of actinomyces with well-developed "clubs" at the periphery in a nodule in the peritoneal cavity of a guinea-pig inoculated with a culture from another guinea-pig. Paraffin section. Low magnification (Wright). (Photograph by Mr. L. S. Brown.)

The bodies described as "coccus forms" are in some cases foreign micro-organisms present in the tissues together with the actinomyces and constituting a mixed infection; in others, and perhaps the majority of cases, they are the products of the degeneration of a filament. The view that any of the coccus-like bodies are spores or are in any wise related to the normal reproduction of the species

has little in its favor and is not countenanced by any feature in the life-history of the organism in culture.

The Cultivation of Actinomyces.—Much perplexity has been caused in the study of this organism—(1) by the error of mistaking Nocardia forms for Actinomyces, and (2) by the failure to recognize the occurrence of mixed infections. A large part of the difficulty of separation has arisen from the fact that Actinomyces is essentially an anaërobe of slow growth, and is therefore not easily freed from the contaminating microbes that are often present in the pus of actinomycotic lesions. Wright recommends the following procedure for the isolation of Actinomyces: The granules, preferably from a closed lesion, are first thoroughly washed in sterile water or broth and then crushed and disintegrated between two sterile glass slides. Bovine material may well be examined microscopically to see if a goodly number of filamentous masses are present, for in some of the granules degeneration has gone so far that no growth can be expected. When filaments are present, the crushed fragments of the granule are transferred with the platinum loop to fluid 1 per cent. dextrose agar (at 40° C.) contained in test-tubes filled to a depth of 7 or 8 centimeters. The material is thoroughly distributed throughout the melted agar and the tube placed in the incubator. Several tubes should be prepared. If the number of filaments introduced is considerable, characteristic colonies of Actinomyces develop in the depth of the agar, especially in a shallow zone about 5 to 12 mm. below the surface. If many colonies of contaminating organisms appear in the tube, it is probably not worth while to continue the attempt at isolation. To guard against possible loss of material from an important case, it is desirable at the outset to place a number of washed granules on the sides of the sterile tubes plugged with cotton and left at room temperature in the dark. Preserved thus for two or three weeks, the contaminating bacteria perish by drying, and in case the original agar tube cultures have proved unsuccessful, the dried granules may be treated in the same manner as were the fresh ones.

When the presence of the characteristic colonies and the absence of a large number of contaminating colonies have been determined, cut out pieces of agar containing colonies by a stiff platinum wire with a flattened oval bent end. With a low power of the microscope

select an isolated colony for transplanting, carefully cut out the small piece of agar containing it, the diameter of the piece not to exceed 2 mm., and transfer the piece with a platinum loop to a tube of sterile broth, where it should be thoroughly shaken up to free it from any adherent bacteria. If there is reason to believe that the small piece of agar has been very much contaminated with bacteria, wash it in a second tube of broth, then transfer with a platinum loop to a tube of melted glucose agar (at 40° C.). Immerse the transplanted piece deep in the agar and place the tube in the incubator. If the colony is capable of growth, and contamination has been avoided, a good-sized colony in pure culture will result, and from this transfers to various culture-media may be made.

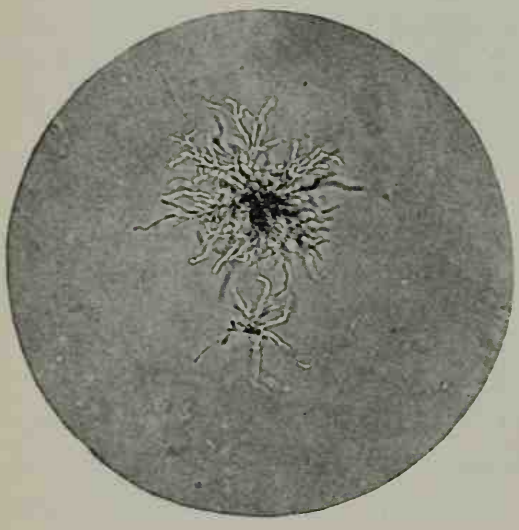

Fig. 114.—Small colonies of actinomyces bovis in the depths of an agar culture (Wright).

The most consistent descriptions of the cultural characters of Actinomyces are found in the work of Wolff and Israel, and in the later monograph of Wright. Discrepancies with the statements of other writers, notably with those of Bostroem, are, according to Wright, most reasonably explained by assuming that the latter worked with impure cultures. Actinomyces grows well in 1 per cent. dextrose agar. In this medium at 37° C. the colonies in the depth, that is, some 10 mm. below the surface, appear as irregularly shaped, opaque, whitish nodules which may reach a diameter of 2 to 3 mm. in a week (Fig. 114). Surface growth upon ordinary nutrient agar, upon dextrose or glycerin-agar, or upon blood-serum, is never luxuriant, and sometimes fails to appear altogether. Stab cultures in dextrose agar give a dense grayish streak of small colonies along the lower part of the line of inoculation, no growth occurring immediately below the surface. In broth a good growth usually occurs in the form of solid, whitish, mulberry-like granules at the bottom of the tube; there is never growth at the surface.

After being under cultivation for some time most strains form flaky, friable, amorphous masses. The broth does not, as a rule, become cloudy. The predilection of this organism for anaërobic growth is shown by these peculiarities.

Upon potato, growth is scanty and not distinctive. Milk is not a favorable medium (Wright). A temperature of about 37° C. seems necessary for successful cultivation of the true Actinomyces. At the ordinary room temperature, when any growth at all takes place, it is very slight. Considerable resistance is shown to drying, most strains being alive after having been dried for fifty days on the walls of the test-tube; some observers have reported continued vitality in cultures dried for upward of a year.

The question whether there is more than one species of Actinomyces has been considerably obscured by the confounding of Nocardia (and Cladothrix?) with this organism, as already stated. Apart from the illegitimate confusion of names thus resulting, some authors have held to a plurality of species, and have, for example, designated organisms from human and bovine sources respectively as Actinomyces hominis and A. bovis. The most recent and thoroughgoing studies, however, indicate that there is no substantial difference in the cultures from man and from cattle, and there is at present no evidence that more than one species is involved in the causation of actinomycosis.

Pathogenesis for Cattle and Other Animals.—In cattle the location of actinomycotic lesions is eminently characteristic. The majority are found in or about the head; the lower jaw and the tongue in particular are affected with great frequency; hence the common names of "lumpy jaw" and "wooden tongue" for this disease. In addition to the growth in the tongue and maxillary bones, actinomycotic lesions occur in the pharynx, in the lungs, in the skin, lymph-glands, and subcutaneous tissue, especially of the head and neck, and occasionally in other organs, notably the udder and liver. The growth of the parasite leads in most situations to the formation of a hard tumor which gradually increases in size and burrows into the adjacent tissues, softening and disintegrating the bony structure of the head, and at the same time forming new tissue, so that great distortion often ensues. The extension of the disease takes place by gradual invasion of the contiguous tissues, metastases being uncommon. When death occurs, it is not, as a rule, due to any

toxic effect, but wholly to the mechanical action of the tumor in pressing upon or occluding the respiratory passages or in interfering with the taking or mastication of food.

In the suppurating mass of the tumor are found the characteristic granules or "glands" (*Drusen*), composed of rosettes, as already described; these structures are so typical that their discovery by microscopic examination in a case of obscure suppuration is sufficient to establish a diagnosis. The new growth—granulation tissue—consists chiefly of epithelioid and spindle-shaped connective-tissue cells; small giant-cells are also sometimes present. To the naked eye, actinomycotic lesions in the lung and udder often resemble tuberculosis nodules, and have undoubtedly at times been mistaken for the latter, but microscopic examination leaves little ground for confusion.

Generalized actinomycosis is rare. When it occurs, the blood-stream rather than the lymph seems to be the channel by which the disease is spread. Secondary abscesses are found mainly in the liver. The horse and the pig are not often affected, the sheep still more seldom. The lesions in these animals are substantially of the same character as those in cattle.

Experimental inoculations of cattle, swine, dogs, rabbits, guinea-pigs, and other animals have given a large proportion of absolutely negative results. In some cases investigators (*e. g.*, Wolff and Israel) have obtained the formation of tumors containing actinomyces colonies with typical "clubs," but in general definite positive results from inoculation are few in number. Wright inoculated eighty-six animals with pure cultures and obtained lesions referable to the micro-organism in but thirty; the lesions were, moreover, insignificant in most cases. A rapid diminution in the virulence of the culture appears to take place under cultivation. Individual susceptibility doubtless plays a large part in determining the course of infection.

Occurrence of Actinomycosis in Man.—This disease is observed in man from time to time, although it is not common. Erving* found records of but one hundred cases observed in America up to December, 1901. Actinomycotic affections of the bone are relatively infrequent, the disease being confined to the softer parts in most cases.

* Erving: Johns Hopkins Hospital Bull., 1902, 13, p. 261.

The tissue changes produced by the presence of the parasite in man are also somewhat different from those in cattle. There are generally a slighter production of new tissue and a more extensive softening and suppuration, which gradually spread to adjacent parts. Generalization of the infection is more common in man than in cattle. The disease may terminate fatally in a few weeks through secondary infection or formation of emboli, or it may drag along in a chronic form for many years. Spontaneous healing has been observed. Compounds of iodin (potassium iodid) have, for unknown reasons, high therapeutic value in actinomycotic affections both in man and in cattle.

Method of Infection.—The parasite of actinomycosis usually enters the body of cattle from the mouth, pharynx, or other point in the upper alimentary tract. This at least is inferred from the peculiar and frequent localization of the disease in the jaw and head, especially since in cattle metastases are rare. There is reason for incriminating the tonsils and carious teeth as starting-points for actinomycotic lesions in man. Although the usual point of invasion thus seems to be quite definitely determined, much uncertainty prevails concerning the immediate source of the invading parasite.

Transmission by direct contagion from one animal to another or from cattle to man has never been satisfactorily established. Many of the cases of actinomycosis reported in man are among persons who have not been engaged in agricultural pursuits and, so far as discovered, have not come in contact with any preëxisting case in animals or man.

A number of observers have encountered fragments of grain (barley or corn) embedded in the soft tissues of the mouth and forming the apparent core of actinomycotic growth. On the basis of such findings the view has been advanced that the natural habitat of the actinomyces fungus is on grain (especially barley—Bostroem*), and that it is introduced into the tissues either through slight scratches or wounds of the mucous membranes of the mouth or throat, or through direct penetration into the tissues of an infected awn or other sharp particle. In support of this conception it is pointed out that the parasite has been reported as commonly found on grain (Johne, Bostroem). Indirectly confirmatory, too, is supposed to be the fact that in a number of cases of actinomycosis in

* Bostroem: Ziegler's Beiträge z. path. Anat., 1890, 9, p. 1.

man there is a suggestive history, such as the habit of chewing grain, nibbling at grain stalks, and the like. It must be said, however, that the evidence that the thread-like fungus found on barley grains is identical with the true actinomyces is quite inadequate, and the wide distribution in nature of the latter parasite remains to be demonstrated. As regards the presence of foreign bodies in actinomycotic lesions, it is not necessary to assume that such a body is the special vehicle of the germ. It may reasonably be maintained that actinomyces is normally present in the mouth, and that its invasion of the tissues is simply facilitated by the irritation caused by the foreign particle. The latter opinion is held by at least one high authority upon actinomycosis (Wright).

Mycetoma or Madura Foot

This disease, as the name implies, usually affects the foot; occasionally the hand is attacked, rarely other parts of the body. It is primarily a disease of warm climates. The part involved shows at first a small swelling, which slowly enlarges and softens, discharging a viscid, slightly purulent fluid in which are minute granular particles. The foot, when affected, becomes greatly enlarged and misshapen (Fig. 115). As in actinomycosis, the bones are often involved. Extension of the infection by the formation of secondary abscesses is said not to occur, and the internal organs are never affected. Three varieties of the malady have been distinguished according to the color of the granules in the diseased tissue: (1) white or yellowish granules, the most common type; (2) a less common black; and (3) a rare red variety. The color of the granules is the only distinguishing mark; the other features are said to be practically identical.

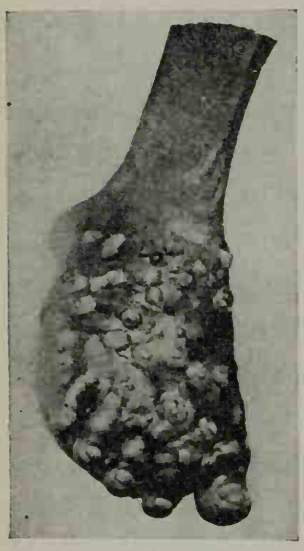

Fig. 115.—Madura foot—mycetoma (Musgrave and Clegg).

White Variety.—It seems probable that some of the cases in which pale yellowish or ochroid granules have been reported were infections with actinomyces. Some observers believe that all cases of the white type are in reality actinomycotic. The granules in

this type are composed of an agglomeration of colonies which, like actinomyces, are made up of a network of filaments. These filaments, moreover, terminate at the margin of the colony in the club-shaped swellings so characteristic of the actinomyces fungus (Fig. 116). The cultural features of the organism isolated from the yellow granules in mycetoma do not, however, correspond, as reported (Vincent), with those of Actinomyces bovis, and it must be regarded as possible that the apparent discrepancies are due to the occurrence of mixed infections, which have elsewhere proved so fruitful a source of error in the study of these organisms.

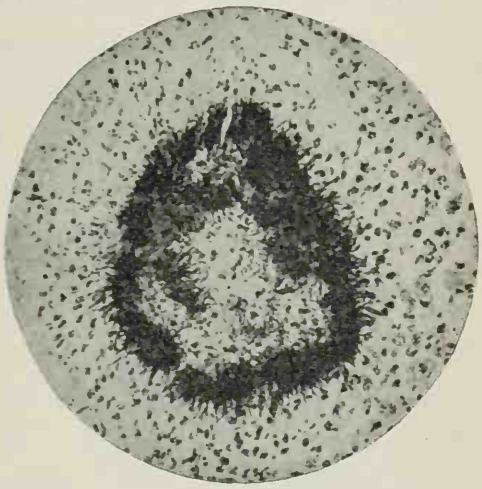

Fig. 116.—Mycetoma. Section of tumor of inoculated dog. × 390 (Musgrave and Clegg).

Black Variety.—The black granule (melanoid) variety of mycetoma, although, according to observers, clinically and anatomically like the more common form in which whitish or yellowish granules are found, has associated with it a fungus very different from actinomyces. The parasite of the dark granules has been studied especially by Wright.* It is a large fungus with thick branching filaments and transverse septa like the hyphæ of the higher molds. The protoplasm of the hyphæ is impregnated with black pigment. Wright obtained ready growth on the ordinary culture-media under aërobic conditions. Spore formation was not observed. This organism must apparently be ranked with the true Hyphomycetes rather than with the Trichomycetes, although little is yet known of its life-history.

Musgrave and Clegg† have successfully carried out inoculation experiments upon monkeys with a pure culture of a fungus found in a case of a white variety of mycetoma. The parasite is distinct from actinomyces and differs in some respects from the organism described by Wright. A very full bibliography of mycetoma is given by these writers.

* Wright: Jour. Exp. Med., 1898, 3, p. 421.

† Musgrave and Clegg: Phila. Jour. Sci., B, 1907, 2, p. 477.

CHAPTER XXVIII

THE BLASTOMYCETES

The organisms known as blastomycetes, saccharomycetes, or yeasts are fungi characterized especially by the mode of multiplication or cell-division called *budding* (*Blastomycetes* = budding fungi) (Fig. 117). The cells are spheroid or egg-shaped in form, and pos-

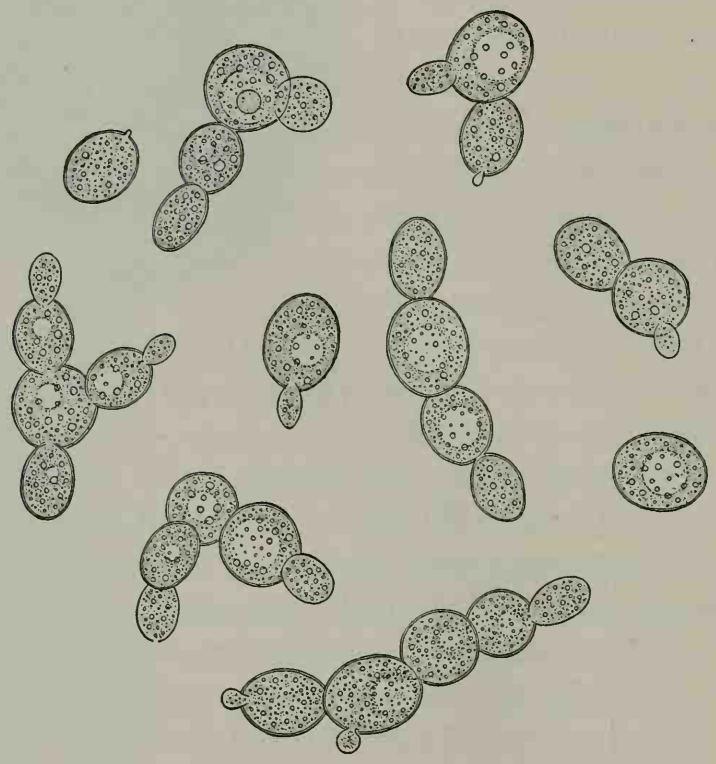

Fig. 117.—Yeast cells. Brewer's (top) yeast actively vegetating. The large internal vacuoles and the small fat-drops are shown, as are also buds, in various stages of development, and the cell-wall. Nuclei not visible (highly magnified) (Sedgwick and Wilson).

sess a well-defined cell-wall of cellulose. As a rule, they are much larger than the bacteria. Many yeasts, or, according to some authorities, all the "true" yeasts, form spores under suitable conditions by endogenous cell-division; the usual number of spores (ascospores) is four (Fig. 118), but some yeast-like organisms have

been found that form eight spores (Schizosaccharomyces octosporus, Beijerinck).

Under certain conditions some of the higher molds develop yeast-like cells which multiply by budding and show many of the characteristics of the common yeasts. The relationship of the yeasts to other fungi has not been clearly made out, and some botanists would deny these organisms any standing as an independent group, regarding them simply as a stage or phase in the life-history of higher organisms. Different names are given to various yeast-like organisms, but without any absolute precision or uniformity. The term *torula* is often applied to certain wild or uncultivated yeasts, usually spherical in shape, non-spore-producing, and with relatively slight fermentive power. *Oïdium* is a name given to some forms that show a marked tendency to grow out into long threads or hyphæ.

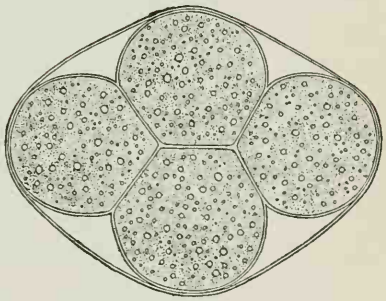

Fig. 118.—Spores of yeast (ascospores). Four spores in a cell of brewer's yeast (Saccharomyces cerevisiæ) (Sedgwick and Wilson).

Yeasts have long been known for their ability to produce alcoholic fermentation, and the technical study of these organisms has been chiefly carried on in connection with brewing and other practical occupations. A variety of familiar processes, such as the rising of dough, are effected through their agency. It is not possible, in the compass of this work, to do justice to the relations of yeasts to the various fermentation industries.*

The action of the enzymes produced by yeasts has been the object of particular interest. Biologists have known for a long time that the cultivated species of yeasts elaborate at least two enzymes, namely, invertase, which has the power of changing or inverting saccharose into dextrose and levulose ($C_{12}H_{22}O_{11} + H_2O = C_6H_{12}O_6 + C_6H_{12}O_6$), and maltase, which splits a molecule of maltase into two

* The reader is referred to the following books, dealing with alcoholic fermentation: Lafar: "Technischen Mykologie," vols. 4 and 5, Jena, 1905–06–07. Jörgensen: "Micro-organisms and Fermentation," trans., London, 1900. Hansen: "Practical Studies in Fermentation," London, 1896. Oppenheimer: "Die Fermente und ihre Wirkungen," Leipzig, 1900.

of dextrose; but for many years it was disputed whether the further conversion of dextrose into alcohol and carbon dioxid was due to a specific enzyme. Buchner* in 1897 first showed that this action also was caused by an enzyme, which, however, unlike invertase and maltase, was closely bound to the cell protoplasm and did not diffuse out into the surrounding medium during the life of the cell. A solution of the alcoholic enzyme or zymase is obtained by rupturing the living yeast-cell, by the method of grinding pressed yeast with sand, and then subjecting the moistened mass to immense pressure. The filtered liquid that is expressed from the yeast cells is able to induce the alcoholic fermentation of a sugar solution. The objection that the fermentation was due to particles of living yeast plasma contained in the yeast juice was met by centrifugalizing the latter, when it was found that the liquid portion possessed the same power of fermentation as that containing the plasma.

The use of pure cultures of yeasts has placed the brewing industry for the first time on a scientific basis. In earlier days the beer wort was commonly invaded by bacteria and "wild" yeasts from countless sources, and the quality of the product was hence uncertain and frequently unsatisfactory. Although Pasteur recognized the share of bacteria in causing "diseases" of beer and wine, he did not fully appreciate the part played by wild yeasts, and it was the service of Hansen, the Danish bacteriologist, to trace much of the common deterioration of beer to the latter source. Hansen showed, further, that it was possible to avoid the interference of wild yeasts by inoculating the wort with cultures of suitable yeasts produced from a single cell under conditions that precluded outside contamination. The method of pure yeast cultures devised by him has been universally adopted, and special forms of apparatus for the development of pure yeast are in general use in all large breweries.†

Pathogenic Yeasts.—The study of the pathogenic activities of blastomycetes dates practically from the discovery by Busse in 1894 of a generalized fatal infection apparently caused by a yeast.‡

* Buchner: Chem. Ber., 1897, 30, pp, 117, 1110, 2668.

† See, for an excellent description of modern brewing, the "American Handy Book of Brewing, Malting, and Auxiliary Trades," Wahl and Henius, Chicago, 1902.

‡ Busse: Centralbl. f. Bakt., 1894, 16, p. 175.

In this case, besides the chief lesion in the tibia, all accessible lymphatic glands were found to be enlarged; the patient died thirteen months after the appearance of the tibial abscess, and the yeast was found in similar abscesses in the ulna and one rib, and also in the lung, left kidney, and spleen. A somewhat similar organism was described by Curtis* as the apparent cause of myxomatous tumors. Gilchrist† was the first to observe and describe a well-defined skin disease, now usually termed blastomycetic dermatitis or oïdiomy-

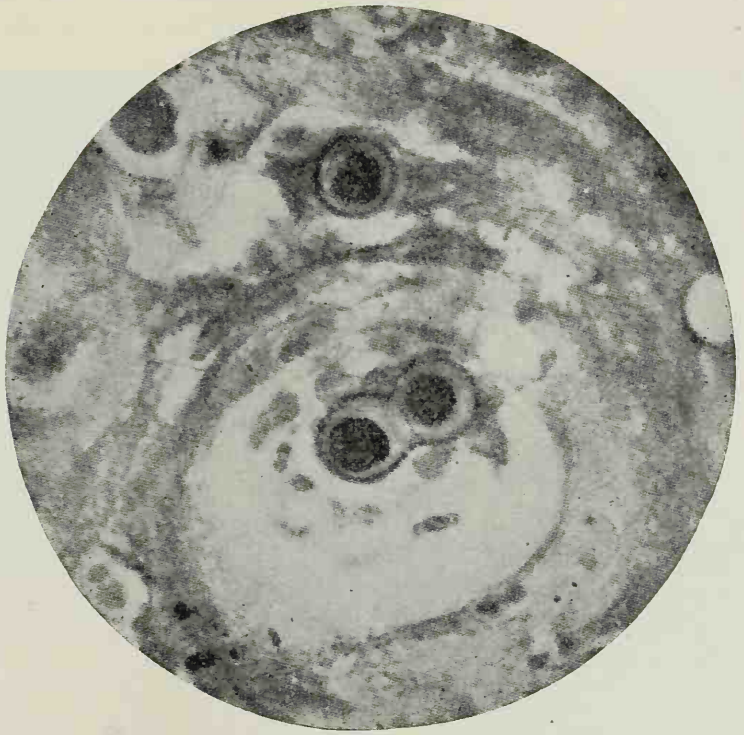

Fig. 119.—Blastomyces. A pair of organisms in an incipient intraepithelial abscess, also a single mature form between epithelial cells. × about 1200 (Ricketts).

cosis, which is caused by a yeast-like organism. Since that time a number of cases of this characteristic skin disease have been reported, especially from the vicinity of Chicago, and the infection has been made the subject of a comprehensive monograph by Ricketts.‡ The organisms occur in the tissues only in the budding, yeast-like stage. The larger cells, which are from 10 μ to 17 μ

* Curtis: Ann. de l'Inst. Pasteur, 1896, 10, p. 449.

† Gilchrist: Johns Hopkins Hosp. Rep., 1896, 1, p. 269.

‡ Ricketts: Jour. Med. Res., 1902, 6, p. 377.

in diameter, are spherical and possess a homogeneous double-contoured capsule, the cytoplasm being sometimes finely, sometimes coarsely, granular and often vacuolated (Fig. 119).

Considerable difficulty is experienced in obtaining cultures directly from fresh tissue, but after growth once appears cultures can be readily maintained on all the usual laboratory media. Freshly isolated cultures grow slightly better on Löffler's blood-serum. On agar after three to seven days small white colonies develop which show under a low power numerous aërial hyphæ. The growth is

Fig. 120.—Blastomycosis. Old partially healed ulcer of the leg (Irons and Graham).

often distinctly mold-like, especially in dry cultures. The substratum becomes penetrated with a mass of mycelial threads and gradually turns to a brown color. Upon glucose-agar there is a somewhat more profuse growth. In broth a fluffy, coherent, globular growth occurs at a fixed point in the fluid, the supernatant fluid remaining clear. Gelatin is not liquefied. Milk turns slightly alkaline and shows some digestion of casein without coagulation. On potato the growth is rather rapid, and in some cultures a large number of budding forms are found with few hyphæ. No gas is

produced in dextrose solutions. Guinea-pigs and rabbits inoculated subcutaneously develop abscesses containing yellowish, cheesy material in which the blastomycetes are present in the budding form. Generalized infection sometimes results. In man, blastomycetic dermatitis follows a substantially uniform course. There is first noticed a small papule, most commonly on the hand, forearm, or face, which yields a viscid pus and gradually enlarges its area (Fig. 120). In a great majority of cases there is absence of lymphatic glandular involvement. The disease may extend over ten or twelve years and cause great cicatricial deformity. Potassium iodid has been used in some cases with distinctly beneficial results.

A number of cases of generalized blastomycosis terminating fatally have been reported. In the majority of these the lung seems to have been the seat of primary infection. Multiple superficial and deep abscesses occur, and both clinical and pathologic findings are rather characteristic.*

A singular and more fatal disease of a similar character has been observed in the San Joaquin Valley on the Pacific slope of the United States.† Although the organism found was at first thought to be a protozoön, and the disease is still termed "coccidioidal granuloma," there is now no doubt that the parasite concerned is a blastomyces or "oïdium." Generalized infections are the rule and are almost invariably fatal. Cutaneous lesions are often entirely secondary and may even be wholly absent.‡

The specific micro-organisms from the Pacific coast, when compared with the blastomycetes from the Chicago cases, show some differences in culture-media, but the distinction upon which stress is mainly laid is that the Pacific coast fungus occurs in the tissues only in the mycelial form, never in the budding form. In pus and in culture-media budding forms very similar to those of "blastomycetic dermatitis" have been observed. The organism of coccidioidal granuloma is also characterized by endogenous spore formation, and proliferation in the tissues appears to be by sporulation.

The disease of the mouth known as parasitic stomatitis or thrush is caused by a micro-organism provisionally classed as an oïdium,

* Irons and Graham: Jour. Infect. Dis., 1906, 3, p. 666.

† Ophüls: Jour. Exp. Med., 1901, 6, p. 443.

‡ Brown: Jour. Amer. Med. Assoc., 1907, 48, p. 743.

Oïdium albicans. Although usually strictly localized, this parasite sometimes invades the internal organs, where it has been found in pure culture in abscesses. A similar yeast-like organism, known as Oïdium lactis, is often found in milk; this form has no pathogenic power.

A number of writers, chiefly Italian observers (Sanfelice,* *et al.*), have sought to establish some relation between blastomycetes and malignant tumors, but the evidence advanced in favor of such a causal connection is totally inadequate. The resemblance between yeasts and the cell inclusions in cancerous tissue seems to be purely superficial.

The problem of the origin of cancer is being attacked at the present time from many sides. The most important recent discovery is that certain spontaneously occurring strains of mouse cancer (adenocarcinomata) can be transplanted from one mouse to another (Jensen, 1902). In all cases the tumor induced in a normal animal by inoculation is due to the multiplication of the transplanted cancer cells and not to the abnormal division of the cells of the inoculated animal. Such transplantation from one animal to another can apparently take place indefinitely, and no diminution in the virulence of the tumor has been noticed after scores of successive transfers. The cause of the indefinitely continued division energy of the cancer cell is not known. Certain observers hold that some as yet undiscovered parasite is responsible for the phenomenon of uncontrolled cell division, but the majority of pathologists are of opinion that the cause is to be sought in the cell itself. An admirable summary of the cancer problem has been given by Ewing.†

* Sanfelice: Centralbl. f. Bakt., 1902, 31, p. 254.

† Ewing: Arch. Int. Med., Feb., 1908.

CHAPTER XXIX

THE HYPHOMYCETES

The organisms known as *Hyphomycetes* or *Eumycetes* are sometimes grouped with the bacteria under the general head of fungi. They are, however, quite distinct from the bacteria, and are more closely related to the higher algæ; perhaps they should be regarded phylogenetically as forms that have lost the chlorophyl they once possessed as the result of taking up a saprophytic or parasitic mode of life.

The filamentous character of the growth is one of the features of this group of organisms. Each filament is termed a *hypha*, and the whole matted, felt-like mass of interlacing filaments is called the *mycelium*. In the lower Hyphomycetes—those showing the closest resemblance to the algæ—each filament is a single, simple, or greatly branched multinuclear cell. In the higher forms the filaments consist of a row of cells set end to end. The lower Hyphomycetes, or Phycomycetes, are further distinguished by their mode of reproduction, which is both asexual and sexual, while the higher fungi probably lack either wholly or in part the sexual mode of development. The common white cottony mold (Mucor mucedo), which grows on damp bread, horse-dung, etc., is a familiar example of the Phycomycetes. In this species the asexual form of reproduction is the more common. From the single-celled, finely branched mycelium rise erect, unbranched hyphæ, near the apex of each of which a septum forms. The tip of the hypha then swells into a globular *sporangium*, within which numerous oval spores develop; the wall of the ripe sporangium ruptures easily and the spores are discharged by the swelling of the gelatinous mass in which they are embedded (Fig. 121). Under certain conditions conjugation of two cells precedes spore-formation (sexual reproduction). Lateral, club-shaped outgrowths occur in neighboring hyphæ and constitute the so-called gametophores. When the tips of two gametophores come in contact, they fuse, transverse septa

are formed, and a *zygospore* is the result. From the matured zygospore a germ-tube arises and may at once develop a sporangium at the apex (Fig. 122).

The higher Hyphomycetes reproduce usually, perhaps exclusively, by asexual spore-formation. In one of the principal groups—Ascomycetes—spores are formed within the hyphæ in asci or tubular spore-cases. In some cases the fertile hyphæ are inclosed within an envelop called the perithecium, which is composed of closely interwoven sterile hyphæ. The very common blue-green mold,

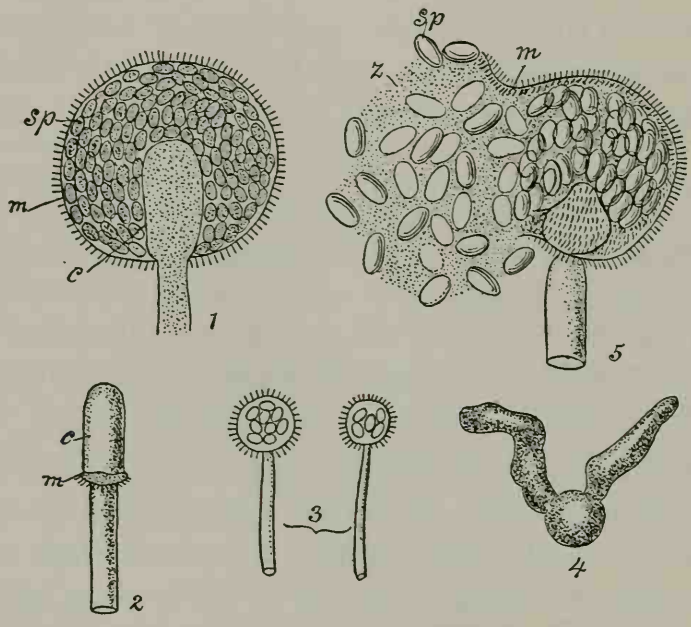

Fig. 121.—Mucor mucedo: 1, A sporangium in optical longitudinal section: *c*, columella; *m*, wall of sporangium; *sp*, spores; 2, a ruptured sporangium with only the columella (*c*) and a small portion of the wall (*m*) remaining; 3, two smaller sporangia with only a few spores and no columella; 4, germinating spores; 5, ruptured sporangium of Mucor mucilaginus with deliquescing wall (*m*) and swollen interstitial substance (*z*); *sp*, spores (after Brefeld).

Penicillium, frequently found as an air-contamination on gelatin or agar plates, multiplies by the formation of gonidia or spores formed directly from the segmentation of portions of the hyphæ; the terminal portion of certain filaments breaks up into finger-like branches, and these branches become constricted into rows of oval spores (Fig. 123). It is still uncertain how far the reproduction of certain of the molds is dependent upon external conditions and how far upon internal relations. Possibly in some cases cell-conjugation precedes the formation of reproductive bodies. There is

no consensus of opinion concerning the classification and interrelationship of these organisms, and in many cases the life-history is incompletely known.

The molds prefer an acid to an alkaline reaction, and are frequently a source of trouble to the housekeeper from their tendency to attack fruit preserves and similar substances. The ability of the hyphæ to force their way through narrow spaces enables these organisms to

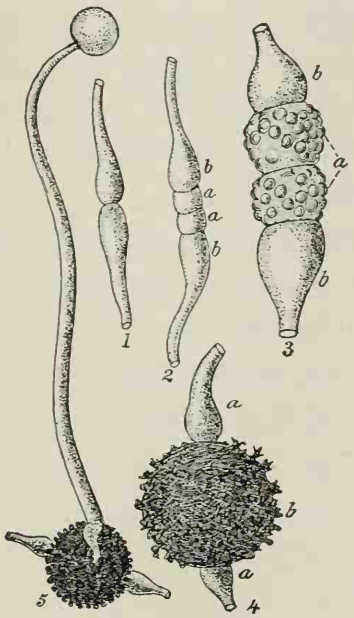

Fig. 122.—Mucor mucedo. Different stages in the formation and germination of the zygospore: 1, Two conjugating branches in contact; 2, septation of the conjugating cells (*a*) from the suspensors (*b*); 3, more advanced stage in the development of the conjugating cells (*a*); 4, ripe zygospore (*b*) between the suspensors (*a*); 5, germinating zygospore with a germ-tube bearing a sporangium (after Brefeld).

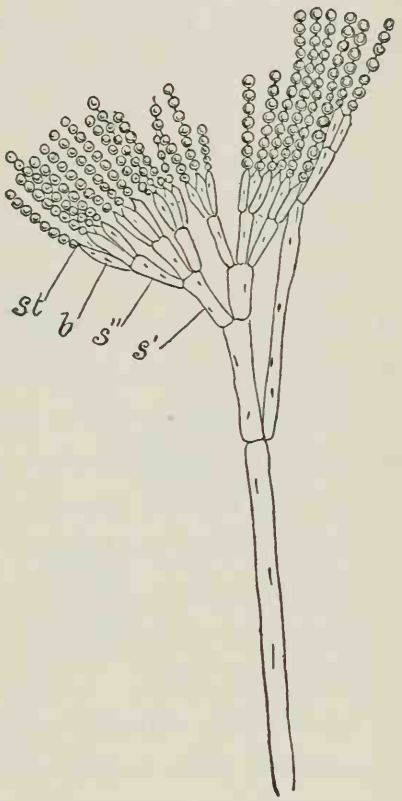

Fig. 123.—Penicillium crustaceum. Conidiophore with verticillate branches, *s'*, *s''*. *b*, *st*, sterigmata abstricting chains of conidia; × 540 (Strasburger).

invade the contents of any receptacle not tightly sealed. Culture-media in bacteriologic laboratories are often contaminated by molds if the cotton plugs are allowed to become moistened, the mold hyphæ readily making their way between the cotton filaments. The spores of molds are well-nigh ubiquitous, and are usually more abundant than bacteria in ordinary air.

Many of the molds are able to attack the tissue of the higher plants and to cause widespread and serious plant diseases. The potato-rot, caused by the fungus Phytophthora infestans, is a familiar example. The infection of rye and other grains with the fungus Claviceps purpurea may entail disastrous consequences for man, since the use of infected grain has been found to cause the condition of poisoning known as ergotism. A poisonous substance called ergot has been obtained from the moldy grain, and its physiologic qualities have caused it to be used in obstetric practice for producing contraction of the uterus. Other grains and vegetable foods are not infrequently attacked by fungi which generate toxic compounds, so that the use of moldy foods by man or by the domestic animals is attended with some danger. In certain cases the fungi producing the poisonous substances have been carefully studied, as in the case of ergot; in others, little is known about them.

While a great many fungi are parasitic upon the higher plants, a relatively much smaller number are known to possess pathogenic properties for the higher animals, including man. Plaut* has divided the fungi pathogenic for man into three groups, according to their pathogenic effects: (1) The molds in the narrower sense (Mucor and Aspergillus); (2) the fungus of thrush; (3) the fungi infecting the skin.

1. Certain widespread and common molds are sometimes found associated with pathologic conditions. In a fatal case in man described by Paltauf† a representative of the genus Mucor was found in abscesses in the lungs, peritoneal cavity, and brain. Instances of infection with several species of molds of the common genus Aspergillus are fairly numerous. Most of the reported cases are among bird-fanciers, especially those having to do with the care of pigeons. These birds are liable to a pulmonary form of aspergillosis, and the evidence is fairly convincing that transmission of the disease from pigeons to man can take place. Experimentally infection has been produced in birds by inhalation of spores. Birds and mammals can also be fatally infected by intravenous inoculation with Aspergillus spores (Fig. 124).

2. An infection of the mucous membrane, usually of the mouth

* Plaut: Kolle and Wassermann's Handbuch, 1, p. 549.

† Paltauf: Archiv f. path. Anat., 1885, 102, p. 543.

of infants, rarely seen in adults, is known as thrush (Ger., *Soor*). The fungous growth is usually localized in the form of white patches on the mucous surface attacked, but generalized infection also may occur, though it is not common. Birds and the lower animals are occasionally attacked spontaneously and may also be artificially infected. A slight degree of immunity may be obtained by repeated inoculation of non-fatal doses of the living parasite, but not with the soluble products of the thrush fungus. Two morphologically distinct varieties of fungi have been found in thrush. One of these, the large-spored, gelatin-liquefying variety, is much more common than the other, and practically all of the recorded observations and experiments relate to this form. The spores or yeast-like bodies found in the large variety are about 5.6 μ long and 4 μ in diameter, while in the small variety they are usually spherical and are from 1.9 to 3.8 μ in diameter. The nomenclature of the thrush fungus is in almost hopeless confusion. Plaut* prefers Monilia candida, though probably the name in most common use is Oïdium albicans.

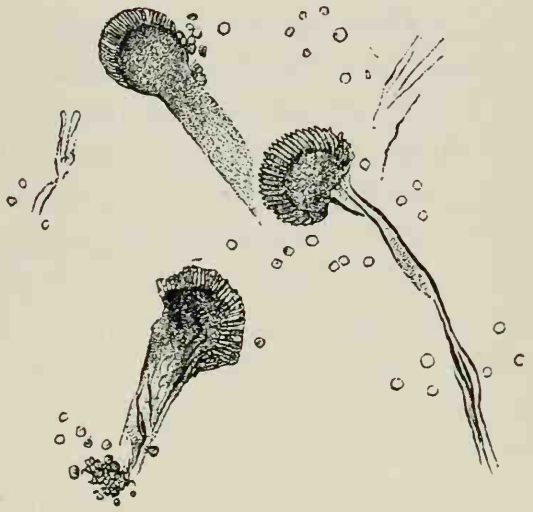

Fig. 124.—Aspergillus fumigatus, from the lung of a parrot (Plaut).

3. The dermatomycoses or skin diseases caused by fungi form a group of respectable dimensions. There is much uncertainty and difference of opinion concerning the nature and systematic position of the various parasites, and a full consideration of the points in dispute is here impossible. In favus, a not uncommon disease of the scalp and other parts of the body, characterized by a dry, yellowish, honeycomb-like incrustation, some investigators would recognize as many as nine different varieties of fungi at times responsible for this condition, while others regard the infection as due to a single highly pleomorphic fungus. The trend of opinion

* Plaut: Kolle and Wassermann's Handbuch, 1, p. 585.

seems toward the latter view. Wälsch* has shown that the parasite of favus in mice can be adapted to growth in the human skin, where it becomes converted into the characteristic fungus of human favus.

The skin affection usually known as ringworm (Herpes tonsurans) is caused by two, possibly more, varieties of the genus Trichophyton. A large-spore and a small-spore variety of the fungus are generally recognized, the latter being the more common. The infection is communicated from man to man, and may also be contracted from the horse, cat, dog, and other domestic animals. The fungi of ringworm and favus are able to penetrate the underlying layers of the skin and to cause pathologic changes in the tissue elements. In this respect they are more highly or more definitely parasitic than certain other fungi which vegetate on the superficial layers of the skin and do not produce marked pathologic lesions. Pityriasis, or Tinea versicolor, a dry, scaly skin eruption, is caused by one of these semi-saprophytic fungi, Microsporon furfur.

* Wälsch: Prag. med. Wchnschr., 1898.

CHAPTER XXX

THE PATHOGENIC PROTOZOA

Introductory.—The Protozoa, the lowest group of the animal kingdom, are especially distinguished from the higher animals, or Metazoa, by the fact that, as a rule, each organism consists of but a single cell. They range in size from organisms scarcely larger than bacteria to organisms several centimeters in length. It is hardly possible at present to define accurately the class of Protozoa. The group is very extensive and heterogeneous, and includes some organisms of great simplicity and some of extraordinary elaboration of structure. The life-cycle of many protozoa is very complex and involves the alternation of sexual and asexual phases. Study of the life-cycle is rapidly changing our conception of relations within the group and of the group itself. Many species are parasitic upon various animals and plants. Doflein* in 1901 enumerated about fifty species of protozoa parasitic or semi-parasitic for man and the larger domestic animals, and a much larger number is now known. Several widespread and serious plagues of domestic animals are due to invasion of the body by various protozoan parasites, and the part played by protozoa in causing diseases of mankind, especially in the tropics, is far more important than was at one time suspected.

The majority of the important protozoan parasites belong to the division of Sporozoa. The Sporozoa, in fact, are exclusively parasitic protozoa, and, excepting bacteria, are the most widely distributed of all parasites.†

The following table gives a general scheme of protozoan classification and the zoölogical position of the more fully identified human parasites.

* Doflein: "Die Protozoen als Parasiten und Krankheitserreger," Jena, 1901, pp. 258, 259.

† Calkins: "The Protozoa," New York, 1901, p. 141.

PROTOZOA

SARCODINA. Naked or cased. Possess changeable protoplasmic processes, called pseudopodia. Reproduce by simple division and by spore-formation. Examples—*Ameba, Foraminifera.* Genus parasitic for man: *Entameba.*

MASTIGOPHORA. Naked or with membrane. Endowed with definite organs of locomotion, the flagella. Many forms possess mouth, contractile vacuole, and well-defined nucleus. Examples—*Peridinium, Noctiluca.* Genus parasitic for man: *Trypanosoma.*

INFUSORIA. Locomotion by means of cilia. Two kinds of nuclei, macronucleus and micronucleus. Reproduce by transverse fission or by budding. Examples—*Paramecium, Opalina, Vorticella, Dendrosoma.* Genus parasitic for man: *Balantidium.*

SPOROZOA. Exclusively endoparasites, taking food by osmosis. No flagella or cilia in adult state. Reproduce by spores. Examples—*Gregarinida, Coccidiida, Hemosporidiida.* Genera parasitic for man: *Plasmodium, Piroplasma, Coccidium.*

The Ameba of Dysentery—Entameba Histolytica

Ameboid organisms have been found in large numbers in the intestinal discharges of persons suffering from a peculiar form of chronic dysentery especially common in the tropics, but by no

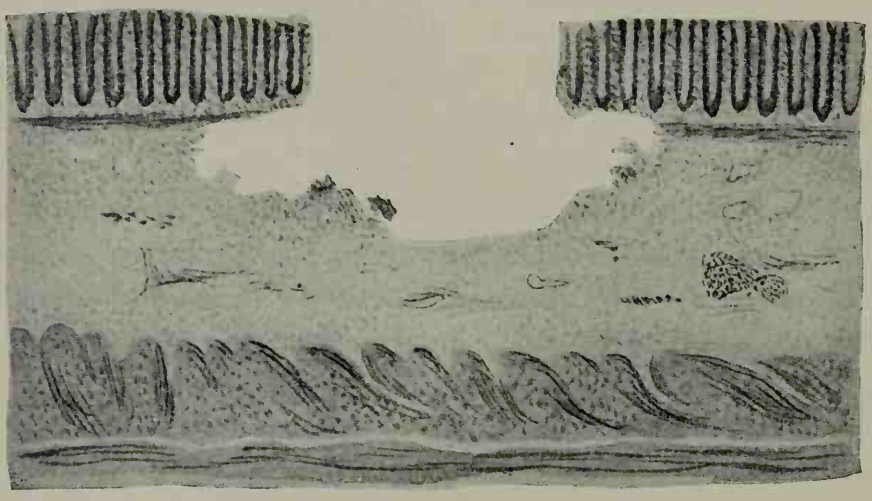

Fig. 125.—Section of an intestinal ulcer (Kartulis, in Kolle and Wassermann).

means rare in temperate countries. In the majority of cases coming to autopsy the ulcerations of the intestinal wall contain amebæ in large numbers, and the histologic appearances at these points indicate an active invasion of the tissues (Fig. 125). Amebæ are also found in the internal organs, notably in the liver, where large abscesses highly characteristic of this form

of dysentery occur in from 20 to 25 per cent. of all cases. These abscesses harbor amebæ in great abundance, and no other microorganism has been constantly demonstrated in these situations culturally or microscopically.* The serum of patients suffering from this form of dysentery does not agglutinate the bacillus of epidemic dysentery (p. 290). The peculiarity of the symptoms and lesions, the localization of the amebæ in the intestinal ulcers and in the characteristic liver abscesses, and the absence of specific bacteria and other parasitic organisms have caused this form of dysentery to be generally ascribed to the pathogenic activity of the ameba. The presence of amebæ in the stools seems to have been first noted by Lambl,† in 1869, and again by Lösch‡ in 1875. Kartulis§ in 1886, in an extensive investigation of dysentery in Egypt, found amebæ in every case, and reached the conclusion that this parasite was the cause of tropical dysentery. Councilman and Lafleur‖ in Baltimore made the first comprehensive study of the clinical and histologic characteristics of this form of dysentery, and their results went far to establish the independent nature of the malady and its connection with the presence of amebæ.

Characteristics.—The ameba of dysentery measures, when at rest, about 15 to 50 μ in diameter. The pseudopodia are short and blunt, the single nucleus is round and vesicular, vacuoles are present in the protoplasm, but a contractile vacuole has not been observed (Fig. 126). Many attempts have been made to cultivate the dysentery amebæ either in pure culture or mixed with a single species of bacterium. Among these may be mentioned those of Kartulis,¶ Tsujitani,** Musgrave and Clegg,†† and Lesage.‡‡ Musgrave and

* The abscesses are not, however, so commonly sterile bacterially as was at one time asserted. Staphylococcus aureus, B. coli, and some other bacteria are found accompanying the amebæ with considerable frequency.

† Lambl: Beobachtungen u. Studien a. d. Gebiete der path. Anat. und Histologie, aus dem Franz-Joseph-Kinder-hospital in Prag, 1860.

‡ Lösch: Virchow's Archiv f. path. Anat., 1875, 65, p. 196.

§ Kartulis: Ibid., 1886, 105, p. 118.

‖ Councilman and Lafleur: Johns Hopkins Hosp. Rep., 1891, 2, p. 395.

¶ Kartulis: Centralbl. f. Bakt., 1891, 9, p. 365.

** Tsujitani: Centralbl. f. Bakt., 1898, 24, p. 666.

†† Musgrave and Clegg: No. 18, Publication of Government Laboratories, Manila, Oct., 1904.

‡‡ Lesage: Ann. de l'Inst. Past., 1905, 19, p. 9.

Clegg have used successfully the following ingenious method. "The sterile ameba medium* is melted and poured into ordinary Petri dishes, the usual precautions being taken. The dishes are then allowed to cool and the medium to become thoroughly hardened. With a platinum loop several rings of pure culture of the organism [for example, S. choleræ] with which it is desired to grow the ameba are made on the surface of the hardened agar, and a small smear inoculation of the mixed culture of the amebæ is placed in the middle of the smaller or central bacterial ring.

"If the necessary precautions have been taken, the amebæ, as they multiply, will generally spread rapidly over the plate, and in passing through the rings of growing bacteria they will lose the organisms with which they started and take up those forming the rings. In from twenty-four to seventy-two hours the protozoa will have passed one or more of the rings, and from such locations they may be taken for transplanting. It sometimes happens that they appear on the first plate in pure cultures with the desired organism, but more generally one or more transplants to the same medium are necessary before this end is reached."

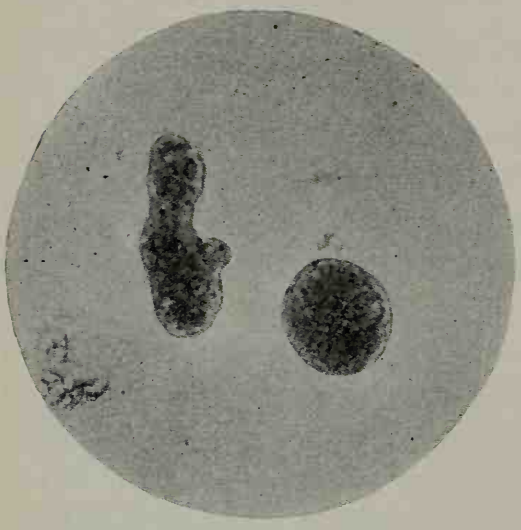

Fig. 126.—Ameba in motion (Kartulis, in Kolle and Wassermann).

Absolutely pure artificial cultures free from bacteria have been obtained by Frosch† and by Walker.‡ Frosch found that by subjecting mixed cultures of bacteria and ingested amebæ to a 20 per cent. solution of sodium carbonate the bacteria were killed but the amebæ remained alive. The amebæ, however, when transplanted, would grow only if supplied with living bacteria. Walker has modified Musgrave and Clegg's method by using concentric rings of dead

* A 2 per cent. agar medium, prepared like nutrient agar, but without peptone and with only 0.03 to 0.05 per cent. salt and 0.03 to 0.05 per cent. extract of beef, 1 per cent. alkaline to phenolphthalein.

† Frosch: Centralbl. f. Bakt., 1897, 21, p. 926.

‡ Walker: Jour. Med. Res., 1907, 7, p. 379.

bacteria in place of living ones. Active amebæ pass through these rings, ridding themselves of living bacteria on the way, and may be obtained in bacteria-free cultures at the periphery. Transplanted cultures will not grow unless provided with living bacteria.

If amebæ are taken from the liver abscesses which apparently contain in some cases natural pure cultures, and introduced into the rectum of the cat, a fatal disease is produced, which bears many marks of similarity to the human form of chronic dysentery. Attempts to infect cats or other animals by feeding dysenteric stools have always failed, but Schaudinn* has succeeded in infecting cats by feeding them with the spores of the dysentery ameba, indicating that natural infection is due to swallowing the spores rather than the vegetative forms. Monkeys in captivity may contract the disease naturally.

Varieties of Intestinal Amebæ.—Amebæ have been found in the intestinal contents of many healthy individuals.† According to Schaudinn, however, the mode of reproduction of the dysentery ameba and that of the normal ameba are entirely distinct. The ameba of the normal intestine (designated by Schaudinn as Entameba coli) multiplies both by simple fission and by spore formation.

The latter phenomenon is preceded by remarkable nuclear changes, which are briefly as follows: Ordinary reduction division of the nucleus first comes to pass, after which conjugation occurs between two daughter nuclei that have arisen from the same mother nucleus. Mitotic division then takes place, and the protoplasm of the cyst comes eventually to contain eight nuclei; finally division of the protoplasm follows and eight small amebæ are formed.

The process of reproduction of Entameba histolytica (as Schaudinn has named the dysentery ameba) follows a different course. Nuclear division of a regular character is entirely absent, or at least has not been observed. Instead, a kind of fragmentation of the chromatin takes place, the remnant of the nucleus itself being expelled from the cyst. Small spherical bodies or spores, 3 μ to 7 μ in diameter, are formed in the cyst, each of these presumably contains some of the finely fragmented chromatin. Schaudinn

* Schaudinn: Arb. a. d. kais. Ges., 1903, 19, p. 547.

† Craig has found amebæ in the feces of approximately 50 per cent. of healthy persons and persons suffering from diseases other than dysentery (Jour. Infect. Dis., 1908, 5, p. 324).

showed experimentally that the spores of E. histolytica are capable of causing serious intestinal symptoms and lesions when fed to cats.

In addition to the great difference between the two species of Entameba in their methods of reproduction, an important morphologic difference, already dwelt on by Jürgens,* is reaffirmed by Schaudinn. In the ameba of normal stools there is little or no differentiation between the inner and outer zones of protoplasm. In E. histolytica, on the other hand, the outer zone or ectoplasm

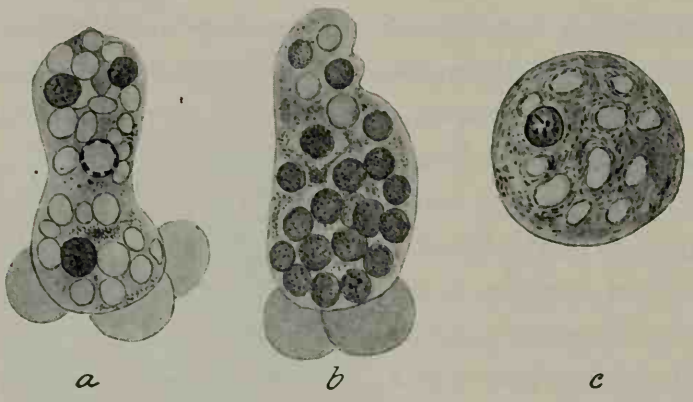

Fig. 127.—Entameba histolytica (Kruse and Pasquale): *a* and *b*, Amebæ as seen in the fresh stools, showing blunt ameboid processes of ectoplasm. The endoplasm of *a* shows a nucleus, three red corpuscles, and numerous vacuoles; that of *b*, numerous red corpuscles and a few vacuoles; *c*, an ameba as seen in a fixed film preparation, showing a small rounded nucleus; × 600.

possesses a stiff, glassy structure and is always sharply delimited from the inner zone. By means of this stiff layer the dysentery ameba is enabled to thrust its way between the epithelial cells into the tissues (Fig. 127).

The life-history of the dysentery ameba outside the human body is essentially unknown, but there is the best of evidence, epidemiologically, that the disease is spread by drinking-water and by raw foods. Musgrave and Clegg† found that cultures of amebæ derived from the water-supply of Manila produced dysentery in monkeys. Unfortunately, the process of sand filtration, which is so effectual a safeguard against water infection with typhoid fever and cholera, has not been found efficacious in removing amebæ from the water.

* Jürgens: "Veröffentl. a. d. Geb. d. Militärsanitätswesens," 1902, 20, p. 110.

† Musgrave and Clegg: No. 18, Publications Government Laboratories, Manila, 1904, p. 93.

There is still much difference of opinion regarding the existence of a distinct pathogenic species of ameba. Walker, as the result of a very careful study, concludes that the amebæ found in the intestine of man in health, and those found in the intestine of man in dysentery, present no noteworthy differences. Craig, on the other hand, believes strongly in the existence of a pathogenic species, and records observations coinciding with those of Schaudinn.

The Trypanosomes

The trypanosomes (Gr., *Τρυπᾶν*, to bore) are a group of free-swimming protozoa occurring in the blood-plasma of mammals, birds, reptiles, and other animals. Similar flagellate parasites are found in the gut of the house-fly and mosquito. Although trypanosomes were observed in the blood of salmon as long ago as 1841, it was not until the investigations by Bruce in 1894 upon the dreaded tsetse-fly disease in Zululand that the pathogenic qualities of these organisms came to light. At the present time at least six well-defined diseases of domestic animals and one or more diseases of man are known to be due to various species of trypanosomes. In addition, trypanosomes have been found in the blood of a very large number of different animal species, in which they seem to occasion little or no harm to the host organism. More than sixty different species of trypanosome have been described. The so-called Halteridium or Hemoproteus, so common in the blood of the owl, crow, and other birds, is, according to Schaudinn, only a stage in the life history of a trypanosome.

The trypanosome found in the common rat is an example of the non-pathogenic or slightly pathogenic group. It may also serve as a morphologic type.

Trypanosoma lewisi.—This parasite infests the blood of wild rats, and in many localities is found in from 25 per cent. to 35 per cent. of all rats captured. In examining a fresh blood-film the rapidly moving trypanosome readily attracts attention by the disturbance of the blood-corpuscles in its immediate neighborhood. At one end is a single, long, free whip or flagellum. The trypanosome usually moves with the flagellum foremost, and in consequence the flagellate end is designated as the anterior end. The posterior extremity of Tr. lewisi is rather sharply pointed, this being one of the characteristics that distinguishes it from other trypanosomes.

The body of the trypanosome itself is spindle-shaped, and a fin-like structure extends from a point near the posterior end of the body to the base of the whip. This fin is the so-called undulating membrane; it plays, perhaps, a more important part in locomotion than the flagellum itself.

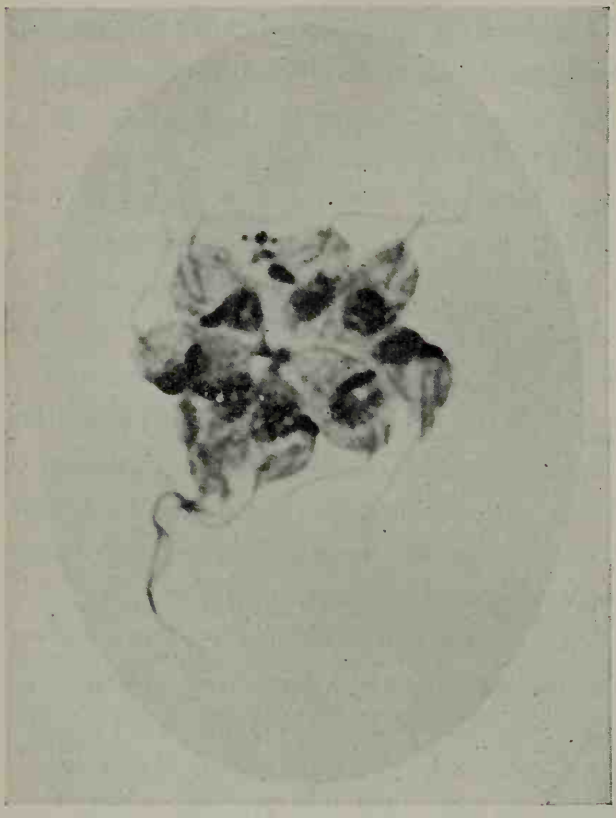

Fig. 128.—Trypanosoma lewisi, eight-cell rosette. Note the long original or parent whip on one of the cells. Several of them show a second whip, growing out preparatory to a further division (MacNeal).

When the trypanosome is stained by the Romanowsky method, a small roundish body is seen near the sharp posterior end. This is the so-called micronucleus or centrosome or blepharoplast. The flagellum is connected with the blepharoplast by a line of stained material which extends along one side of the protozoön to the anterior end, and it is supposed that the blepharoplast functions as a motor center. In the rat trypanosome the macronucleus, or nucleus proper, is situated near the anterior end. The length of Tr. lewisi is about 25 μ or approximately three and one-half times the diameter of a red corpuscle.

When the cell is about to divide, it lengthens, becomes somewhat stouter, and at the same time the nucleus draws near to the blepharoplast. Usually the blepharoplast divides first and the nucleus later. The body of the cell then undergoes fission and gives birth to a young trypanosome, which may at once become detached from the mother cell. In all cases division is longitudinal. Transverse division never occurs.

In some cases division takes place after a fashion analogous to

the segmentation of the malarial parasite, resulting in the formation of a rosette, composed of from four to eight small trypanosomes with their flagella pointing outward (Fig. 128). Such rosette formation is apparently due to a retardation of the division of the protoplasm, the nuclei and the blepharoplasts dividing first, without corresponding separation of new individuals. The typical pathogenic trypanosomes do not develop rosettes in the blood. No evidence of true conjugation in trypanosomes has yet been discovered.

Injection of a small quantity of rat blood containing trypanosomes into a healthy rat produces an infection in about three to four days. As a rule, the trypanosomes disappear from the blood of inoculated animals within two or three months after infection, but in exceptional cases they may persist much longer. Unlike nearly all other known trypanosomes, Tr. lewisi is peculiar to one kind of animal—the rat—and cannot be transferred to any other species. White rats as well as the common wild rats are susceptible. Usually the infected rats seem to suffer little harm from the presence of the parasite, but sometimes the infection is severe, and in young animals death may result.

When a rat has once become free from the parasite, it is found to have acquired an active immunity and cannot be reinfected. The blood of animals that have received a number of injections possesses protective properties, and the injection of immune serum from such animals will prevent infection in normal rats. Transmission of the rat trypanosome from infected animals to healthy ones can take place through the bite of insects, such as rat fleas, lice, etc.

In 1903 Novy and MacNeal* succeeded in cultivating the rat trypanosome in pure culture outside of the body. The culture-medium employed is a blood-agar composed of equal parts of defibrinated rabbit blood and nutrient agar. The agar is melted and cooled to about 50° C., after which the rabbit blood is added and thoroughly mixed.

"The tubes thus prepared are allowed to set in an inclined position, after which they are at once inoculated. It is essential that the surface of the medium be moist and soft, and if this is not the case, the tubes should be placed in an upright position until some water of condensation accumulates at the bottom. The initial

* Novy and MacNeal: Contributions to Medical Research, dedicated to V. C. Vaughan, Ann Arbor, 1903, p. 549.

culture usually requires a week or more, although not infrequently fairly rich growths may be obtained in three or four days" (Novy).

By the use of this medium Novy and his associates have kept trypanosomes under cultivation for several years, carrying them in this time through nearly one hundred generations. The trypanosome of nagana (see below, Tr. brucei) has also been cultivated artificially in a similar manner.* Trypanosomes found in birds can be grown with especial ease by this method.

The more definitely pathogenic species of trypanosomes may now be briefly considered.

Trypanosoma evansi.—A disease of horses and camels characterized by remitting fever, anemia, and edema is common in India, where it is known as *surra*. This affection has been shown to be due to the presence of a species of trypanosome. The same or a very similar form of trypanosomiasis also occurs in other parts of Asia and in Africa. In the Philippines it has caused much loss among horses and cattle. Experiments have shown conclusively that flies (*Stomoxys, Tabanus*) are able to transmit the disease, provided they bite within a few hours after feeding on the infected host. These insects are probably mere mechanical carriers.

Trypanosoma brucei.—The early explorers of the continent of Africa found their movements greatly interfered with by a disease that affected their beasts of burden, and that destroyed horses, mules, and oxen in large numbers. This disease was attributed by the natives to the bite of an insect called the tsetse-fly, and European observations served to confirm the existence of such a connection. The tsetse-fly disease is commonly called by the native name nagana. It has been observed especially in Zululand, but occurs likewise in other parts of Africa. Nearly all of the large mammals seem susceptible to natural or experimental infection, but man appears to be naturally immune.

In the blood of animals suffering from nagana Bruce† discovered a trypanosome. This trypanosome has been obtained in cultures by Novy and MacNeal,‡ and extended experiments have been carried out with the isolated organisms.

* Novy and MacNeal: Jour. Infect. Dis., 1904, 1, p. 1.

† Bruce: Preliminary Report on the tsetse-fly disease or nagana in Zululand, Durban, 1896.

‡ Novy and MacNeal: Jour. Infect. Dis., 1894, 1, p. 1.

The tsetse-fly, *Glossina morsitans* (Fig. 129), seems to be the only insect whose bite is able to convey the nagana infection, since ordinary biting insects that have fed on infected animals are not able to communicate the disease to healthy subjects. This being so, it is singular that the tsetse-fly seems to act merely as a mechanical carrier of the trypanosome, since its bite can convey the disease only within forty-eight hours after the fly has fed on a diseased animal. There is reason to believe that the parasite exists in the blood of big game in parts of Africa, and that the fly becomes infected from these animals and transmits the disease to horses and cattle. As Bruce expresses it, the reservoir of the disease is found

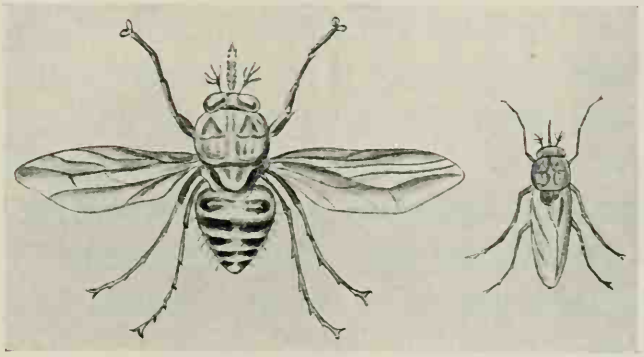

Fig. 129.—Tsetse-fly, Glossina morsitans. Small figure is natural size of the fly (Kolle and Hetsch).

in the wild animals. It is said that the extermination of the larger wild herbivora in parts of southern Africa has rendered the tsetse-fly disease relatively uncommon.

Trypanosoma equinum.—A disease known as mal de Caderas, which is prevalent in parts of South America, and attacks especially horses, is due to a trypanosome which resembles in general size and form the other pathogenic trypanosomes, but is easily differentiated by the apparent absence of a blepharoplast; as a matter of fact, this structure is present, but is very inconspicuous. Mal de Caderas is characterized especially by paralysis of the hindquarters and by the almost complete absence of the edemas which are usually present in nagana and surra.

Trypanosoma dimorphon.—A disease of horses in Senegambia, presumably transmitted by biting flies, is apparently due to the presence of a trypanosome. This trypanosome occurs in two phases—a long and a short form. The most characteristic feature of the trypanosome in the Gambian horse disease is the absence of

a free whip, a condition due to the prolongation of the cell protoplasm to the very tip of the flagellum.

Trypanosoma theileri.—The trypanosomiasis of cattle in South Africa, known by a variety of names, such as gall-sickness or gal-ziekte, malaria of cattle, etc., is caused by an unusually large trypanosome (30 μ to 65 μ in length), about the size of the bird trypanosomes. Trypanosoma theileri, like Tr. lewisi, seems to be limited to one host, since inoculations of animals other than cattle have failed. Gall-sickness, like most of the other trypanosomiases, seems to be transmitted by the bite of a particular insect; in this case, *Hippobosca rufipes* is the one incriminated.

Trypanosoma equiperdum.—A disease of horses met with in parts of Europe, and also reported from western Canada, is caused by a trypanosome very similar to the other pathogenic forms. This disease has long been known by the name of dourine, or mal du coit. The disease is usually of a chronic character, the animal becoming gradually paralyzed, and dying, as a rule, within from two to ten months. A noteworthy feature of the disease is that it is spread, so far as known, exclusively by sexual congress, and not by biting insects. Experimentally the disease can be readily communicated to the horse, ass, dog, and rabbit.

Trypanosoma gambiense.—In addition to these definite infections of the lower animals, a form of human trypanosomiasis is known which prevails extensively among the natives of southern Africa and also affects Europeans. This is the terrible disease known as sleeping sickness. It has been estimated that between 1896 and 1906 from 400,000 to 500,000 natives in the Congo region perished from this pestilence.

The parasite, Trypanosoma gambiense, resembles very closely the trypanosomes of surra and nagana. The disease is conveyed by the bite of a fly, *Glossina palpalis*, belonging to the same genus as the tsetse-fly that carries the nagana of Zululand. The early experiments seemed to indicate that transmission was merely mechanical and was due to the direct injection of contaminated blood by a fly that had recently (within three days) fed on an infected animal. The experiments of Kleine and others, however, show that after a period of about twenty days the fly again becomes capable of communicating the infection, and is hence probably a true host for the trypanosome.

Sleeping sickness is characterized by two stages, in the first of which the trypanosomes are found in the blood, although always in small numbers; the pulse and respiration are accelerated, but in general the symptoms are mild. Glandular enlargements are an early and constant feature, and the trypanosomes are practically always found in the enlarged glands. After a variable length of time the second stage of the disease is entered upon; this is characterized by the symptoms which have given rise to the name of sleeping sickness. The patients become dull and apathetic, great weakness of the limbs develops, and emaciation is usually extreme. Finally, a condition of coma ensues and is followed by death.

Some kinds of monkeys (macaques) may be successfully inoculated, and develop symptoms very similar to those seen in man. The larger domestic animals are rather refractory to inoculation, but dogs and cats are quite susceptible. White rats are also readily infected.

In parts of Africa the disease is terribly prevalent. Dutton and Todd* found that in some villages from 30 to 50 per cent. of the population were infected. So far as known, sleeping sickness is invariably fatal. A number of cases among Europeans have been reported; one investigator has lost his life in studying this disease. Experimental treatment of animals with a compound of arsenic (atoxyl) and an anilin dye named trypan-red has been found to modify the course of the infection, in some cases effecting an apparent cure. Treatment of human cases of sleeping sickness with these substances, however, has so far been only partly effectual. In recent years sleeping sickness has greatly extended its ravages in Africa, and is now prevalent in regions previously exempt.

Tr. (?).—A disease known as kala-azar, dum-dum fever, or tropical splenomegaly, occurring in parts of India, and at one time regarded as a malarial cachexia, has been ascribed by several observers to a trypanosome-like parasite.† This disease is of very long duration and is highly fatal. In 1903, Leishman‡ described certain peculiar bodies found in the spleen of a patient suf-

* Dutton and Todd: "First Report of the Expedition to Senegambia," 1902. "Trypanosomiasis," Liverpool School of Tropical Medicine, Memoir II, Liverpool, 1903.

† See Rogers, Milroy Lectures, Brit. Med. Jour., Feb. 23, Mar. 2, and Mar. 9, 1907.

‡ Leishman: Brit. Med. Jour., 1903, 1, p. 1252.

fering from this form of protracted fever, and a similar observation was made independently by Donovan* shortly after. Subsequent investigations by Rogers† and others have shown that the "Leishman-Donovan bodies" pass through certain developmental phases in infected blood drawn from the body and mixed with sodium citrate. Opinion differs as to the exact nature of these organisms, but they appear to be very similar to certain flagellate organisms found in birds and mosquitos ("Herpetomonas," "Crithidia"). Their exact relationship to the trypanosomes remains to be established. There is reason to think that the parasite of kala-azar is transmitted to man by the bite of the bedbug, and Patton has observed that the parasite undergoes developmental changes in the stomach of bedbugs fed on kala-azar patients. When taken into the stomach of this insect the parasites are still in the intracellular stage. After being liberated by the digestion of the human cells they become flagellated and may form small rosettes. Conjugation processes probably occur, but have not yet been made out. Animal inoculations with the kala-azar parasite have failed.

Micro-organisms morphologically indistinguishable from those found in kala-azar have been found in the affection known as Oriental sore, Delhi boil, or tropical ulcer. Although apparently seen by Cunningham in 1885, they were first accurately described and pictured by J. H. Wright.‡ Many observers consider these parasites to be piroplasmas rather than trypanosomes.§ Although there is a close morphologic resemblance between the Wright bodies and the Leishman bodies, the very different nature of the pathologic conditions with which they are associated would seem to indicate that the two organisms are not identical.

The Malarial Parasites

Introductory.—The writings of antiquity contain frequent mention of the clinical manifestations of malaria, but although the disease was known for centuries, surprisingly little real information was acquired concerning its significant etiologic features until the last quarter of the nineteenth century. Perhaps the most important

* Donovan: Ibid., 1903, 2, p. 79.

† Rogers: Lancet, 1905, 1, p. 1484.

‡ Wright, J. H.: Jour. Med. Res., 1903, 10, p. 472.

§ See, for example, Marzinowsky, Ztschr. f. Hyg., 1907, 58, p. 327.

of the early observations upon the natural history of malaria consisted in noticing that the disease prevailed especially in some localities and not in others. In fact, the geographic and topographic distribution of the malarial fevers is so peculiar that it excited the languid curiosity of many ancient peoples and caused them to set afloat various surmises to account for such distribution, which, however, were in the main unprofitable and fruitless.

The advent of bacteriology caused the study of malaria to be taken up from the new point of view, and at first several enthusiastic workers reported the discovery of certain bacteria which they deemed to bear a causal relation to the disease. These reputed findings failed to be confirmed. It was not until November 6, 1880, that the true malarial parasite, a protozoön of the class Sporozoa, was discovered by Laveran,* a French military surgeon stationed in Algiers. In 1885 Golgi† described in detail the life-history of the parasite of quartan fever, and later brought forward strong evidence that the parasites of tertian and estivo-autumnal fever could be morphologically differentiated from the quartan form. Golgi also showed that the malarial chill or paroxysm always coincides with the sporulation in the blood of a brood of parasites.

The Asexual Development of the Malarial Parasites.—In the human body the malarial micro-organism passes through certain regular phases of development within the red blood-corpuscles. The parasite in its youngest recognizable stage appears to be attached to the corpuscle as a small, glassy, oval, rounded or ring-like body with ameboid movements, which proceeds to burrow slowly into the substance of the corpuscle, increasing in size at the latter's expense. After attaining its maximum development the mature and full-grown parasite, which varies in size according to the species, undergoes a segmentation of its cell-substance, giving rise first to the appearance of a rosette or mulberry-like body within the corpuscle, and leading eventually to the formation of small rounded spores or merozoites. The young merozoites are liberated by the ultimate disintegration of the corpuscle, and on being set free fasten themselves to new red corpuscles and begin once more their cycle of development (Fig. 130). The setting-free of the merozoites

* Laveran: Bull. Acad. de méd., 1880, ser. 2, 9, p. 1346.

† Golgi: Arch. per le Sci. med., 1886, 10, p. 109; Ztschr. f. Hyg., 1891, 10, p. 136.

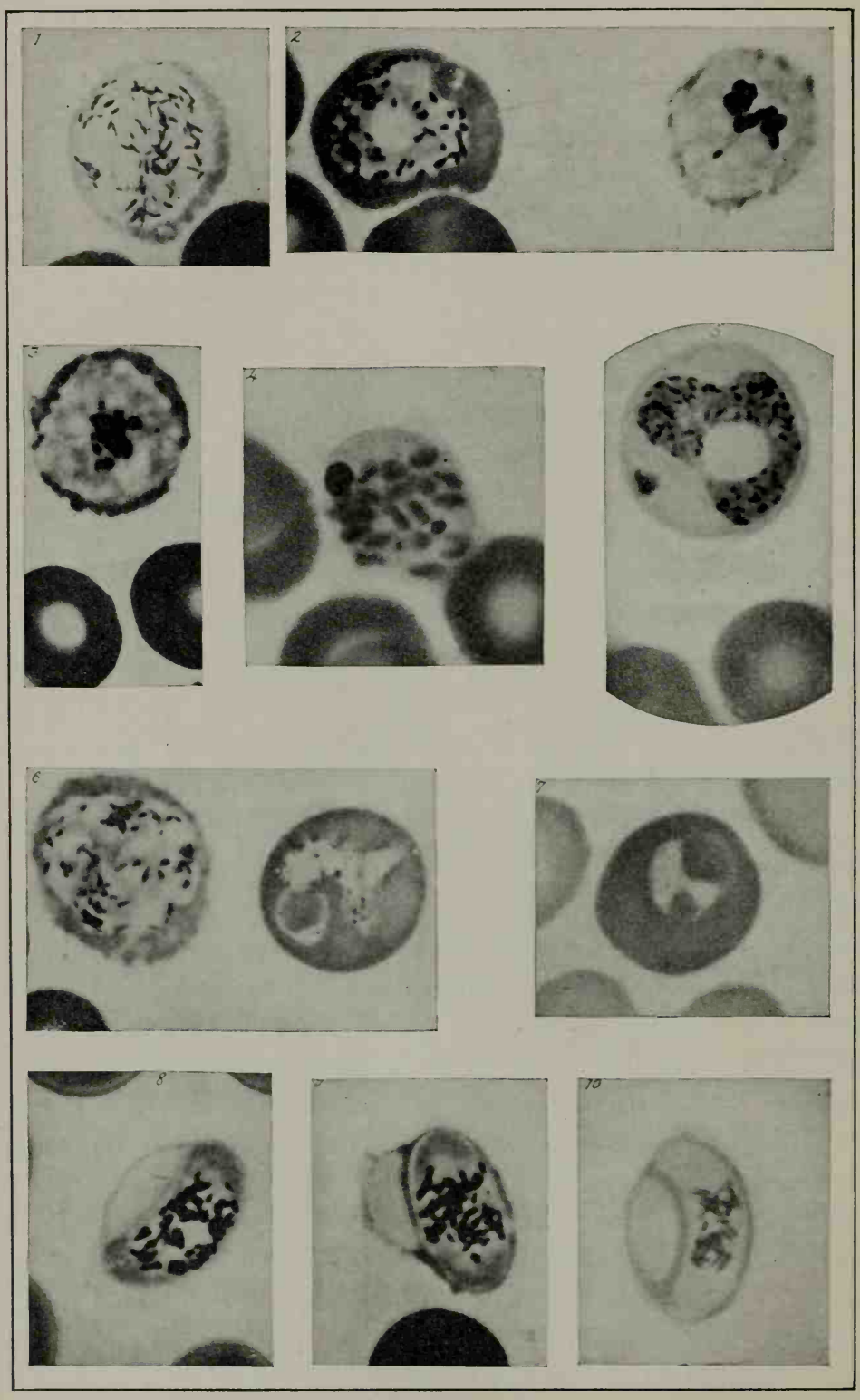

Fig. 130.—Malarial parasites: 1 to 5, Various stages in the life-cycle of the tertian parasite; 6, on the left, an adult tertian parasite in a red blood-corpuscle; on the right, a young tertian parasite and a hyaline form of the estivo-autumnal parasite in a red blood-corpuscle; 7, hyaline form of the estivo-autumnal parasite in a corpuscle; 8, 9, 10, crescentic and ovoid forms of the estivo-autumnal parasite in red blood-corpuscles (Wright and Brown).

is practically coincident with the appearance of the chill or malarial paroxysm, and the remarkable periodicity of the malarial attack is thus conditioned by the time necessary for the development of the protozoön. Only the asexual mode of development here outlined has been observed to occur in the human body.

Morphology of the Different Varieties of the Malarial Parasite.—Three and possibly four varieties of the malarial parasite can be distinguished, and most observers are agreed that the three forms are biologically distinct organisms. Each of these varieties is found associated with a type of fever possessed of a clinical individuality: namely, (1) tertian malarial fever, (2) quartan malarial fever, (3 and 4?) estivo-autumnal fever, quotidian and tertian varieties. The tertian and quartan fevers are the more common malarial fevers of temperate countries, are rarely fatal, and are readily amenable to quinin. The estivo-autumnal fever is more prevalent in the tropics, is more deadly, more irregular in course, and relatively refractory to treatment.

1. *The Tertian Parasite* (*Plasmodium vivax*).—The time required for the asexual development of the tertian parasite is forty-eight hours. The paroxysms accordingly appear on alternate days, or, according to the Roman method of reckoning time, the first attack is followed by the recurrent attack on the third day, whence the name of tertian fever. The full-grown tertian parasite is quite large, and may even reach a diameter nearly double that of the corpuscle. The young parasites show active ameboid movement. Twelve to twenty-four spores—about sixteen on an average—are produced.

2. *The Quartan Parasite* (*Plasmodium malariæ*).—The quartan parasite completes its asexual development in seventy-two hours, the malarial attacks taking place therefore at intervals of three days. The young parasite manifests a less active ameboid movement than the tertian form, and the pigment is of a more coarsely granular character. The size of the adult quartan parasite does not exceed that of the red corpuscle. The number of the merozoites produced is usually eight, but may range between six and fourteen.

3 and 4. *The Parasites of Estivo-autumnal Fever* (*Plasmodium immaculatum or falciparum*).—Although there is still no general agreement as to the existence of one or more types of estivo-autumnal parasites, many and perhaps most of the students of malaria in

tropical countries are of the opinion that there are two varieties, the quotidian* and the tertian. Both varieties are much smaller than the parasites of simple tertian and quartan fever, and never reach more than about three-fourths of the diameter of a blood-corpuscle. Differentiation is said to rest on the following characteristics:

The *quotidian form* of the estivo-autumnal parasite shows an active ameboid movement and has a small amount of pigment. The cycle, from segmentation to segmentation, takes twenty-four hours. At the time of spore-formation the diameter of the parasite is about one-fourth that of the red corpuscle. Six to eight very small spores are formed. Peculiar crescent-shaped bodies are found in the blood only in the estivo-autumnal fevers. They are the forerunners of the sexual phase, and under suitable conditions, such as exist in the stomach of the mosquito, become oval, then round, and finally develop into male (microgametes) and female (macrogametes). In the quotidian fever the crescents are relatively short and plump.

The *tertian form* of the estivo-autumnal parasite has a less active ameboid movement and a more abundant supply of pigment than the quotidian form. The asexual development cycle occupies forty-eight hours. When segmentation begins, the parasite is about twice as large as the quotidian form (one-half the diameter of the corpuscle). The spores number from ten to fifteen or even twenty. The crescents of the tertian form are more slender and the ends are sharper than in the other type.

The great majority of the "pernicious" and fatal cases of malaria are due to the estivo-autumnal parasite. Tertian infections are said to be much more common than quotidian. The estivo-autumnal fevers are more irregular in character than the ordinary tertian or quartan types.

The following tabulation shows the main difference between the four forms of parasite:

* Some cases of malarial fever in which the attacks recur at twenty-four-hour intervals may be due not to a specifically distinct parasite, but to infection with more than one brood of parasites. Thus a double tertian infection in which brood A matures on the first and third day, brood B on the second and fourth day, and so on, or a triple quartan infection, or a double quartan together with a single tertian, may give rise to the quotidian type of fever (Golgi).

DIFFERENCES BETWEEN THE FOUR FORMS OF MALARIAL PARASITES

Parasite of:	Asexual Cycle Completed in:	Effect on Red Corpuscle.	Size and Shape of Mature Parasite. Number of Merozoites Formed.	Sexual Form.
Tertian Fever	Forty-eight hours.	Corpuscle swollen, blanched, and spotted (Romanowsky's stain). Finely granular pigment formed by metamorphosis of hemoglobin.	One and one-half times the diameter of the corpuscle, mulberry-shaped. Twelve to twenty-four young parasites formed by segmentation.	Crescents lacking. Male gametocyte (spheres) about two-thirds as large as female gametocyte, which is about one and one-half times as large as a red corpuscle.
Quartan Fever	Seventy-two hours.	Corpuscles normal; coarsely granular pigment formed.	Approximately the size of the corpuscle, daisy-shaped. Six to fourteen spores formed.	Crescents lacking. Gametocyte about as large as red corpuscle.
Estivo-autumnal Fever — Quotidian Form	Twenty-four hours.	Corpuscles greenish. Sometimes shriveled and darkened Small amount of pigment present.	Always much smaller than the corpuscle, usually about one-fourth the diameter. Six to eight spores.	Crescents present. Gametocytes at most three-fourths the size of a red corpuscle. Crescents short and plump.
Estivo-autumnal Fever — Tertian Form	Forty-eight hours.	Corpuscles affected in much the same way as by quotidian form. Pigment more abundant.	Larger than quotidian parasite, about half the diameter of corpuscle. Ten to twenty-four spores.	Crescents slender and with pointed ends.

The Sexual Phase of the Parasite.—The malarial parasite, as has been stated, passes only its asexual phase of development within the human body. A complicated sexual phase is consummated within the body of the mosquito. After the sexual development is completed, the parasite may again enter the body of its mammalian host, borne along with the fluid injected by the mosquito in the act of biting, and forthwith embark upon a new asexual cycle. Zoölogically considered, man is the intermediate host of the malarial parasite, and the mosquito (Anopheles) its true host. The elucidation of the remarkable relations subsisting between man, the mosquito, and the malarial parasite is due to Ronald Ross,* an English army officer, stationed in India at the time of his investigations.

The steps that led up to this discovery are of peculiar interest. The occasional occurrence in the blood taken from malarial patients of crescent-shaped bodies, "flagellated forms," and other deviations from the strict asexual type received the easy interpretation by some writers of a mere degeneration phenomenon. The observation, however, that the flagellated bodies were not seen in freshly drawn blood, but only appeared after the blood had been exposed for a short time to air, caused some investigators (Manson†) to adopt the hypothesis that the advent of these bodies marked an abortive attempt on the part of the parasite to enter upon the sexual stage. As a corollary to this hypothesis, the assumption appeared warranted that the sexual phase of the parasite was passed in the body of some suctorial insect, suspicion eventually fastening on the mosquito.‡ As a result of this reasoning, Ross undertook his researches in India. Other investigations were pointing in the same direction. In 1897 MacCallum§ found that the so-called flagella sometimes seen attached to the parasites of bird malaria were in reality male sex cells, which entered the larger spherical female cells of the avian malarial parasite, a process presumably one of fertilization.

* Ross, Ronald: Indian Med. Gaz., 1898, 33, pp. 14, 133, 401, 448.

† Manson: Brit. Med. Jour., 1894, 2, pp. 1252, 1306; "Tropical Diseases," London, 1900.

‡ King had previously advanced arguments in support of the mosquito-malaria hypothesis in a paper that seems at the time to have attracted little attention (Popular Science Monthly, Sept., 1883).

§ MacCallum: Lancet, 1897, 2, p. 1240.

Ross, who also studied bird malaria, obtained convincing evidence in the first place that the malarial parasite of birds underwent an intricate sexual development within the body of a certain kind of mosquito (Culex), and found that the infection could be communicated to normal birds by means of the bite of infected mosquitos. He further observed that the human malarial parasite could not develop in the body of Culex, but did develop in the stomach of another variety of mosquito (Anopheles). Finally (August, 1897) he recognized that certain pigmented cells found in the stomach of mosquitos (Anopheles) that had been fed with the blood of human malarial patients were developmental phases of the parasite.*

Conclusive demonstration that malaria could be transmitted by the bite of infected mosquitos was afforded by Bignami† at Rome, and also in an especially striking manner by Manson in London. The latter investigator, who had never previously suffered from malaria and who lived in England, a country free from indigenous malaria, allowed himself to be bitten by some forty mosquitos that had been shipped from Rome after sucking blood from a case of tertian malaria. An attack of the disease followed, and typical tertian parasites were found in the blood.

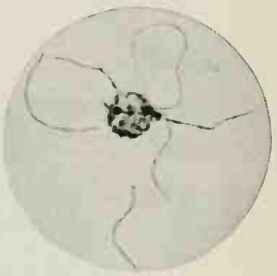

Fig. 131.—Microgametocyte, showing flagella (Koch).

The sexual development of the parasite within the body of the mosquito may be briefly outlined as follows. Two sexual elements or gametes develop among the so-called spores. The precise period in the asexual cycle at which the gametes first appear in the blood of an infected person is not known. The male cell (microgametocyte) develops four to eight delicate, hyaline filaments (microgametes) (Fig. 131); one of these enters one of the large spherical and granular macrogametes (female cell), and effects a true fertilization (Fig. 132). The copula (zygote, oökinete) resulting from their union penetrates the stomach wall of the mosquito, where it becomes encysted, and increases greatly in size, so that the stomach wall

* Ross: Brit. Med. Jour., 1898, 1, pp. 550, 1575, 1607.

† Bignami: Lancet, 1898, 2, pp. 1461, 1541.

of an infected mosquito becomes studded with numerous* wart-like protuberances (Fig. 133). Small spherical bodies (sporoblasts) are formed in the interior of the encysted parasites. Finally these give rise to myriads of delicate filamentous bodies (sporozoites) which eventually are liberated by the rupture of the cyst and are carried by the lymph to all parts of the body of the mosquito; they accumulate especially in the poison gland (a modified salivary gland) (Fig. 134). On the average eight to ten days are needed to complete the sexual cycle, provided a

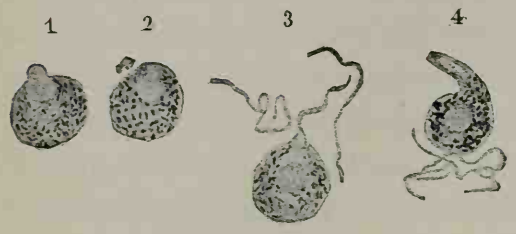

Fig. 132.—Fertilization, tertian parasite: 1, Extrusion of nuclear substance by macrogamete; 2, macrogamete with divided nucleus; 3, entrance of microgamete into the macrogamete; 4, zygote (Schaudinn).

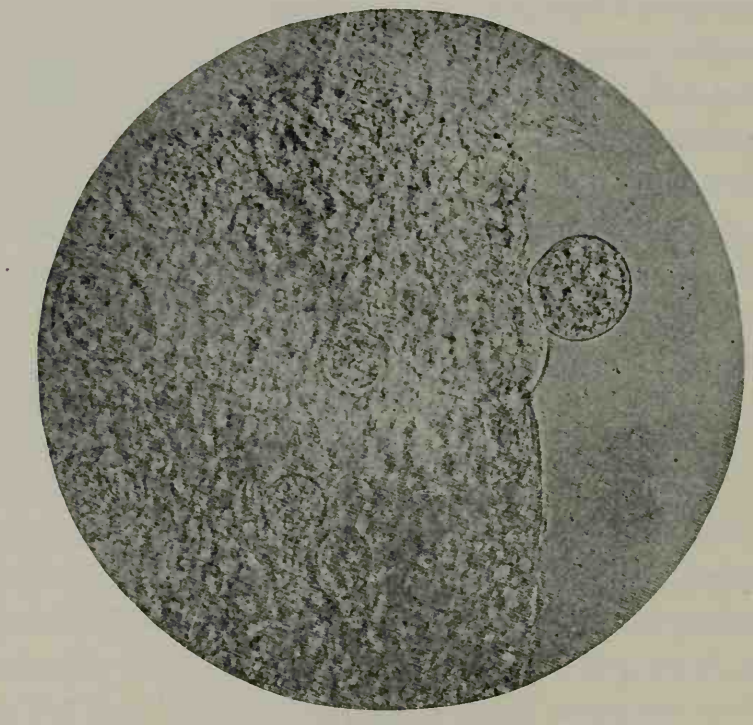

Fig. 133.—Malarial zygotes in stomach wall of the mosquito. High power (Manson).

suitable temperature prevails. When a mosquito possessing an infected poison gland bites a human being, the parasites in the

* Grassi estimates that five hundred may develop in the stomach walls of a single insect.

sporozoite stage are discharged into the wound together with the poison, and are then able to enter once more upon their asexual cycle.

As has so often happened in the course of parasitic evolution, the malarial parasite is restricted, so far as known, to certain definite hosts. There is no evidence that the parasites of human malaria can invade the red corpuscles of any other mammalian species. It is also true that the genus of mosquito known as Anopheles is

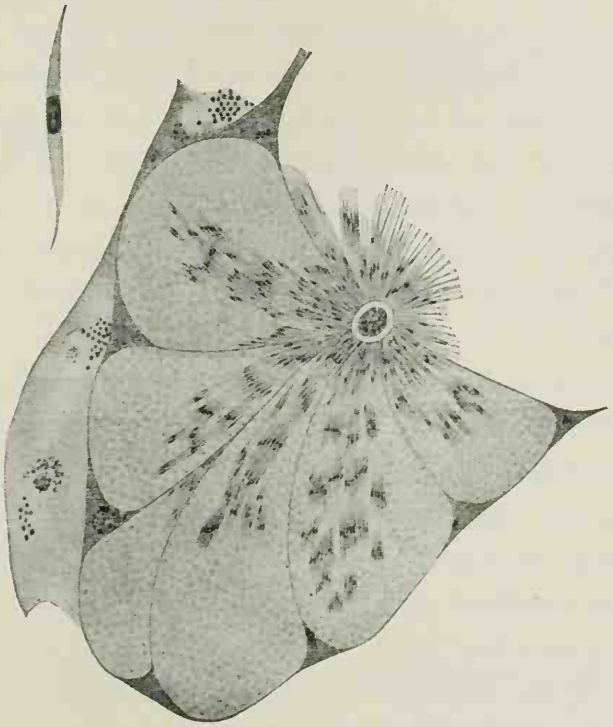

Fig. 134.—Section of salivary gland of a mosquito, Anopheles. Sporozoites (Grassi).

the only kind of mosquito that has been shown capable of harboring this specific protozoön.*

* Not all species of Anopheles furnish an equally good soil for the propagation of the malarial parasite. This is notably the case with one species common in India (*A. rossi*), which, although experimentally capable of conveying infection, is very rarely, if at all, infected under natural conditions. James found that among 736 individuals of *A. rossi* caught in native huts, not one was infected, although about one-half of the native children in the neighborhood harbored the malarial parasite, and another less common species of Anopheles (*A. culicifacies*) was infected in proportions varying from 4.6 to 8.7 per cent. (Zschr. f. Hyg., 1903, 43, p. 218).

One species of Anopheles at present most common in many parts of the United States (*A. punctipennis*) has not yet been shown to be capable of transmitting malaria, although the species often associated with it (*A. maculipennis*) has been definitely incriminated.

The main differences between the genus Anopheles* and the closely related and very common genus Culex are shown in the accompanying figures (Fig. 135). The chief generic distinction is based upon the length of the palpi, which in the female Anopheles are as long as the proboscis and in the female Culex are always much shorter. Many species of Anopheles are easily distinguished from Culex by the possession of spots on the wings,† but this is not a universal distinction. A further difference between the two genera consists in the position assumed while at rest, the body of Culex, as a rule, being parallel to the surface on which the mosquito is resting, while that of Anopheles forms a more or less acute angle with the surface. In Anopheles, furthermore, the head, thorax, and abdomen form one straight line, whereas in the resting Culex the thorax and abdomen form an angle with the head and proboscis (Fig. 135). The eggs and the larvæ of the two genera can be readily distinguished.

The habits and distribution of Anopheles explain many of the most characteristic features in the epidemiology of malaria. Many species of Anopheles are almost wholly nocturnal in their habits, rarely biting by day, hence the greater liability of contracting malaria during the night hours. The great abundance of Anopheles in certain localities and at certain seasons accounts for certain long-observed peculiarities in the geographic and seasonal distribution of the disease. The connection of malarial fevers with marshy localities, the prevalence of the disease in country districts rather than in cities, the often striking exemption of persons on board vessels lying off a malarious coast, the frequent breaking out of the disease in consequence of extensive soil excavations and disturbance of natural water-courses,—such as occurs, for example, in railroad construction,—all these idiosyncrasies of malarial fever can be explained through the creation or maintenance of breeding-grounds for Anopheles, or through the opportunities afforded Anopheles for access to malarial patients and subsequently to uninfected

* Some authorities have split up the original genus Anopheles into ten or more new genera, but general agreement concerning the classification of these organisms has not yet been reached.

† This is true of all but one of the seven species reported from the United States, and this exception, *A. barberi*, is a very rare species.

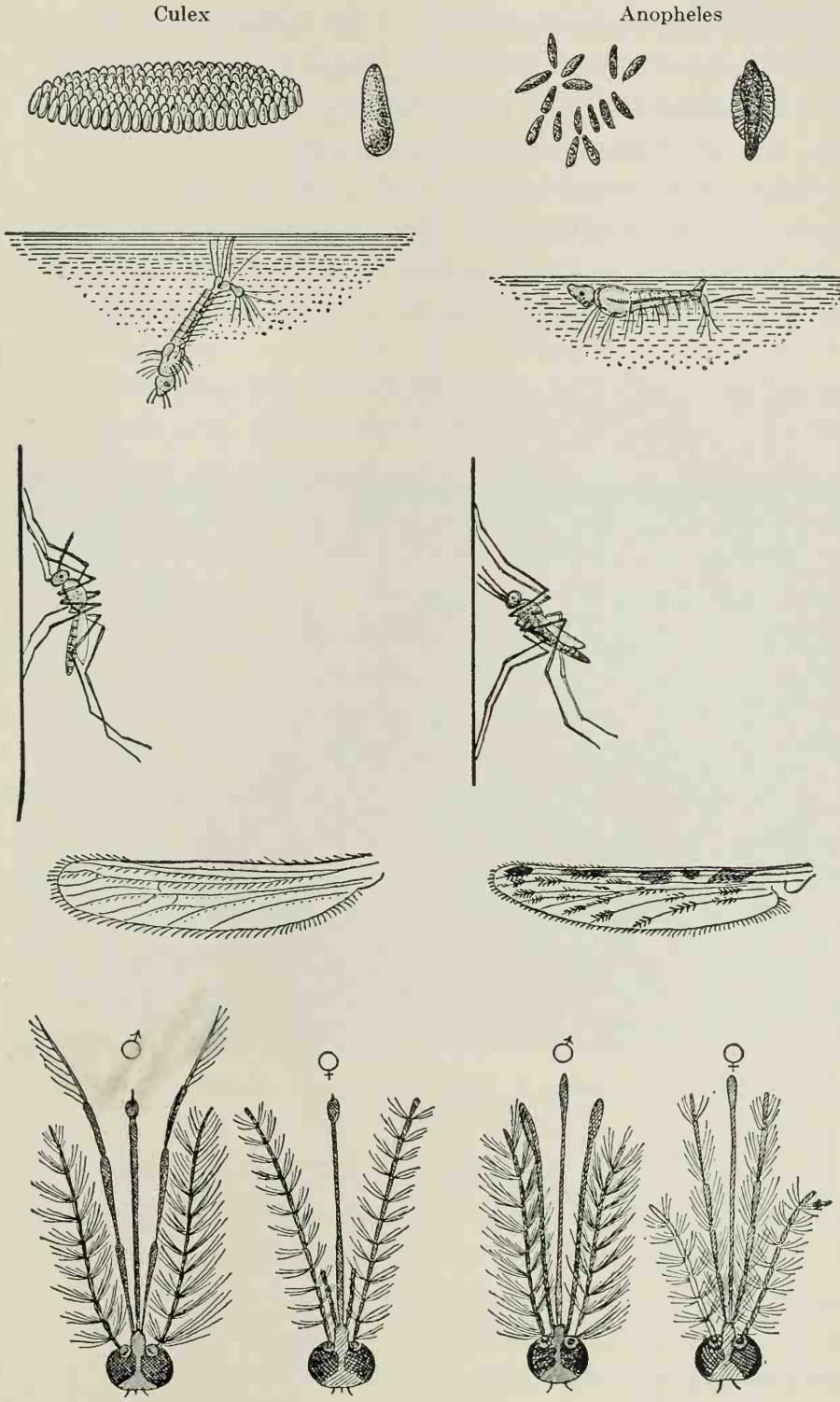

Fig. 135.—Comparison of Culex and Anopheles. Eggs, larvæ (note position), position of insects at rest, wings, heads showing antennæ and palpi (Kolle and Hetsch).

persons. Many other factors influence the causation of malaria because they affect the insect host of the malarial parasite rather than the parasite itself. Summing up the matter of malarial infection, it can be said that the proximity of a malarial patient is never a source of danger unless Anopheles mosquitos occur in the immediate environment, and, conversely, the Anopheles mosquito is not to be feared unless there are present in the neighborhood persons bearing the malarial parasites in their blood.

Prophylaxis.—Accepting the theory that malaria is conveyed

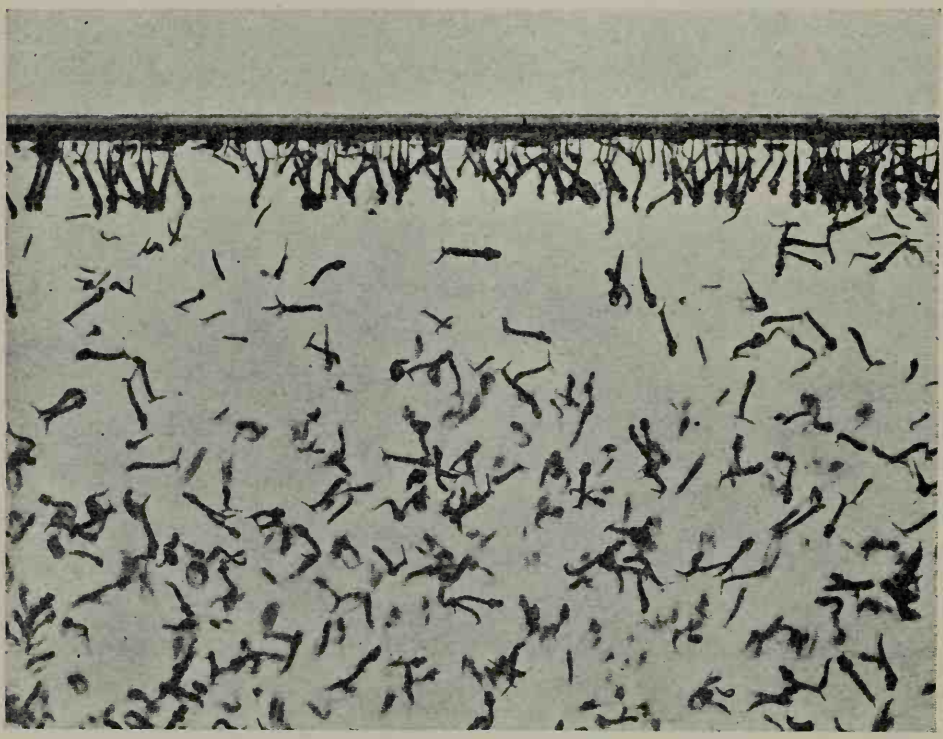

Fig. 136.—Mosquito "wigglers"—larvæ and pupæ—in the water. Life size (Underwood).

only through the bite of an infected mosquito, there are at least three ways in which the spread of the disease may be combated.

1. The parasite when within the human body may be injured or destroyed by means of the systematic and continued administration of quinin, thus preventing the infection of mosquitos and breaking this link in the chain of causation. This is the method advocated especially by Koch,* and in certain regions, as in the case of several small islands near the coast of New Guinea, it has been employed with great success in stamping out the disease. It

* Koch: Deut. med. Wchnschr., 1899, 25, p. 69.

is clear that when the available supply of malaria parasites is cut off, the bite of Anopheles can no longer convey infection, since there is absolutely no evidence that Anopheles can become infected with the malarial protozoön in any other way than by sucking blood from an infected human being. It is the opinion of Koch and others, who have devoted much study to the conditions in tropical countries, that from the point of view of community-infection, malaria can be effectively dealt with only in this way. The cost of the quinin necessary for such an undertaking is of course great, and this has been urged as an objection against the method, but in a few instances the total outlay for quinin has been actually diminished as compared with the previous consumption of this drug, owing to the systematic mode of procedure that has been introduced. Koch has pointed out that in tropical countries it is almost exclusively the native children that harbor the malarial parasite; the adult natives, owing apparently to the severe infections to which they have been subjected in childhood, are nearly all immune. Quinin acts most energetically upon the young parasite, and in accordance with this fact has been found to be most efficacious in the tertian and quartan fevers when administered in a single large dose during the decline of temperature, that is to say, shortly after the young parasites have been set free in the blood. In the estivo-autumnal fever, where less regularity exists, and where different broods of parasites come to maturity at different times, smaller doses at frequent intervals have been found more useful.

Considerable individual protection in a malarial district may be obtained by taking one gram of quinin on each of two successive days with five- to eight-day intervals ("gram-prophylaxis"), this procedure being more effective in the opinion of many than taking 0.5 gram of quinin every five days ("half-gram prophylaxis"). It is claimed that the gram-prophylaxis may be modified to advantage by taking the daily gram in five separate portions (0.2 gram) at suitable intervals (Nocht's method).

2. A second method that has been ardently advocated as suitable for the extirpation of malaria consists in directly attacking the mosquito host. This mode of conducting the campaign against malaria has been especially urged by Ross and other English authorities. It is believed that a given locality can be effectively rid of Anopheles either by the treatment of breeding pools with kero-

sene or some other larvacide, or by the total destruction of the breeding-places. In some localities considerable success has been achieved in freeing a given locality from Anopheles, and in several parts of the United States the whole mosquito plague has been greatly reduced by the use of such methods as are advocated by Ross and others. It must be said, however, that many observers familiar with tropical conditions regard the attempt at mosquito destruction in those parts of the world most scourged by malaria as absolutely hopeless.

3. The spread of the disease can be checked in some measure by the consistent use of mosquito netting, mosquito-proof houses, and other mechanical devices for shielding malaria patients against the bite of mosquitos, thereby preventing the infection of Anopheles. In the same way healthy individuals may be safeguarded from the bite of infected mosquitos. That a high degree of protection can be afforded by suitable precautions against mosquito attack is proved by the experience of Sambon and Low, who spent several months during the malarial season in a carefully constructed hut in the Roman Campagna. These investigators breathed the same air and drank the same water as the other inhabitants of this malaria-stricken region, but, owing to the precautions taken in the matter of retreating at nightfall to their mosquito-proof sleeping apartments, they remained entirely exempt from the disease. This form of mechanical prophylaxis has been applied on a large scale in Italy to the homes of railway employees, customs officials, and others compelled by their vocation to dwell in malarial regions, and is said to have given "résultats vraiment magnifiques" (Celli). It is not, however, always possible for tropical residents so to order their lives as to protect themselves consistently from the bite of mosquitos, and although the liability to malarial infection may be somewhat lessened by the conscientious employment of mosquito netting and other protective devices, the danger cannot be altogether avoided. In regions where malaria is not very common, and particularly in temperate climates, much can doubtless be done to prevent the extension of the disease by educating the community to the desirability of thoroughly screening malaria patients and shielding them so far as possible against mosquito bite.

The inference is clearly justified that no one of the three methods advocated for prophylactic purposes can be reasonably neglected.

Protection against mosquito bite, abatement of the number of mosquitos in a given locality, and diminution in the number of persons harboring the malarial parasite will all surely lead to a reduction in the prevalence of malaria, and any improvement will be cumulative.

Other Hemosporidia

Various malarial parasites infecting birds of various species have been described under the name of **Proteosoma** (Haemoproteus). These are quite common and of cosmopolitan distribution. The life-history of Proteosoma has been worked out with some degree of completeness and is very similar to that of Plasmodium, in which genus many naturalists place these forms. The sexual phase of Proteosoma, like that of Plasmodium, is accomplished in the body of the mosquito, but in a different genus (Culex, not Anopheles). The gametocytes are bean shaped (see p. 455). Canaries frequently succumb to artificial infection with Proteosoma, while sparrows, which are often found infected under natural conditions, die but rarely.

Various protozoa parasitic within blood-corpuscles are also found in frogs, turtles, and other cold-blooded animals. **Drepanidium,** a very common form occurring in the frog, is perhaps the best known of these. Either the sexual or the asexual mode of development of most of these blood parasites remains unknown, and their zoölogical affinities are consequently uncertain.

The Piroplasmas

The parasitic protozoa now known under the generic name of *Piroplasma** (Lat., *pirus*, a pear) were first discovered in 1889 by Theobald Smith† in the blood of cattle suffering from a disease known as Texas fever, tick fever, or bovine malaria. The disease known in South America as *La Tristeza* is identical with this affection. Other piroplasmas have since been found in the blood of various animal species.

* The name Babesia is regarded by Calkins (Protozoölogy, New York, 1909, p. 272) and some other protozoölogists as having claims of priority for the title of this genus.

† Smith, Theobald: Bulletin No. 1, Bureau of Animal Industry, Washington, D. C., 1893.

Piroplasma bigeminum.—Texas fever is characterized especially by destruction of the red blood-corpuscles, accompanied by hemoglobinuria; the spleen is greatly enlarged, and the liver extensively affected. The disease, which is peculiar to cattle, is common in the southern United States, and occurs also in South America, parts of Europe, and Africa. A remarkable feature in the natural history of Texas fever is that cattle raised in a disease-ridden district may be to all appearances entirely healthy, and yet when imported into uninfected territory, transmit the disease to susceptible animals.

The piroplasma is found in the blood of infected animals, where it occurs within the red corpuscles. In the acute form of the disease

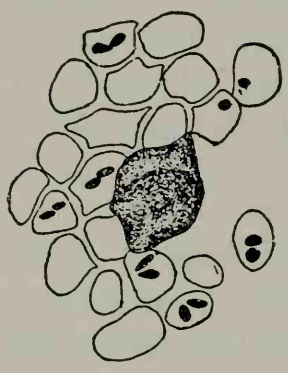

Fig. 137.—Piroplasma bigeminum in blood from kidney (Smith).

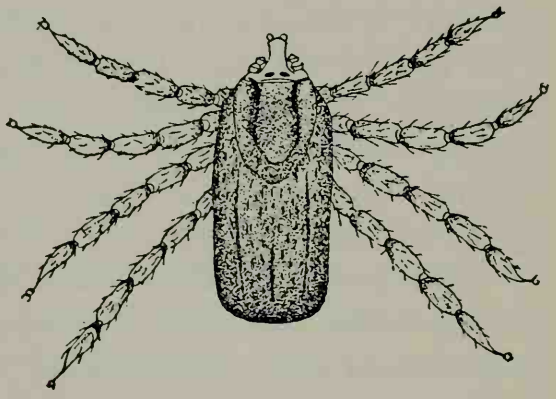

Fig. 138.—Cattle tick, Boöphilus bovis. Sexually mature female after last moult (Smith).

the parasites appear as pear-shaped bodies, usually two in number in each corpuscle, with their pointed ends in juxtaposition (Fig. 137). In the chronic type they are very small, rounded, coccus-like forms, generally but one in a corpuscle. Ameboid movements are observed in certain stages. The parasites are seen in fresh preparations with difficulty, but they stain distinctly with alkaline methylene-blue and other dyes.

That some connection existed between the cattle tick (*Rhipicephalus annulatus*) and Texas fever was long suspected by practical stockmen, but such a connection was first demonstrated by the work of Smith and Kilborne. So far as known, infected ticks are the only means by which the disease is spread. Ticks that mature upon the bodies of animals containing piroplasmas in their blood *never attack another animal*, but drop to the ground after the usual fashion of these insects, and lay their eggs. The eggs hatch in about

three weeks, and the young ticks in the larval and nymphal stages crawl upon the bodies of cattle that may be grazing in the tick-infested pasture (Figs. 138 and 139). It has been experimentally proved that the bite of these young ticks, descended from piroplasma-infected mothers, is able to communicate the infection. The adult insects themselves do not pass from infected cattle to healthy ones, but transmit the disease only indirectly by way of their progeny. Smith and Kilborne have shown that cattle from the permanently infected territory, though otherwise healthy, carry the piroplasmas of Texas fever in their blood. These facts explain many singular features in the epidemiology of the disease, such as the breaking out of Texas fever in northern herds upon the introduction of apparently healthy cattle from the south, the sickening of northern cattle imported south and not brought into contact with southern cattle, but pastured in tick-infected fields, and the inability of cattle sick with Texas fever to communicate the disease unless they are at the same time infected with ticks.

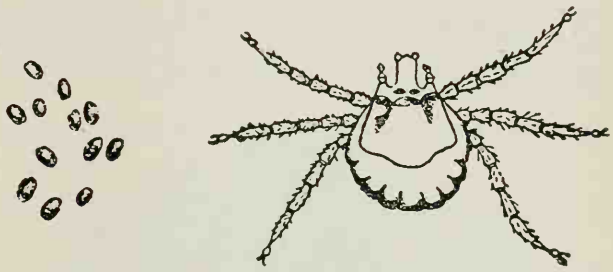

Fig. 139.—Boöphilus bovis; eggs and young tick, just hatched (Smith).

Piroplasma parvum.—A disease of cattle in Africa clinically similar to Texas fever has been attributed by Koch and others to a parasite of the piroplasma group. The organism in question is smaller than Pir. bigeminum, and presents other distinct points of difference. The sickness, known as Rhodesia fever or East Coast fever, is spread by tick bite and resembles Texas fever in many respects. Mixed infections with the coast fever and Texas fever parasites seem to be not uncommon and have caused much confusion. Koch has described developmental phases of Pir. parvum observed in the stomach contents of the tick, among them what seems to be a kind of conjugation.

Piroplasma canis.—A piroplasmosis of the dog has been observed in France, Italy, South Africa, and some other places. Possibly the European and African parasites are different. The infection, which is termed "malignant jaundice" or "bilious fever,"

is accompanied in its acute form by anemia, hemoglobinuria, and usually some jaundice. The parasite is intracorpuscular and is very similar to the parasite of Texas fever. Only dogs are susceptible to this disease, all other animals proving refractory. As is the case with other piroplasmoses, the disease in the dog is conveyed by tick bite. The African variety of the disease cannot be conveyed by the larva, but only by adult ticks raised from the eggs of infected eggs. In the European form the larvæ or nymphs as well as the eggs may become infected directly from the dog. "The variations in regard to the mechanism of transmission, especially the time factor, indicate that obligatory changes in the life-history takes place in the insect body" (Calkins). The nature of these changes has not yet been made out. Probably a sexual cycle occurs in the tick. The serum of recovered animals renders virulent blood innocuous, and the same is true, although in lesser degree, of the serum of naturally immune animals like the sheep.

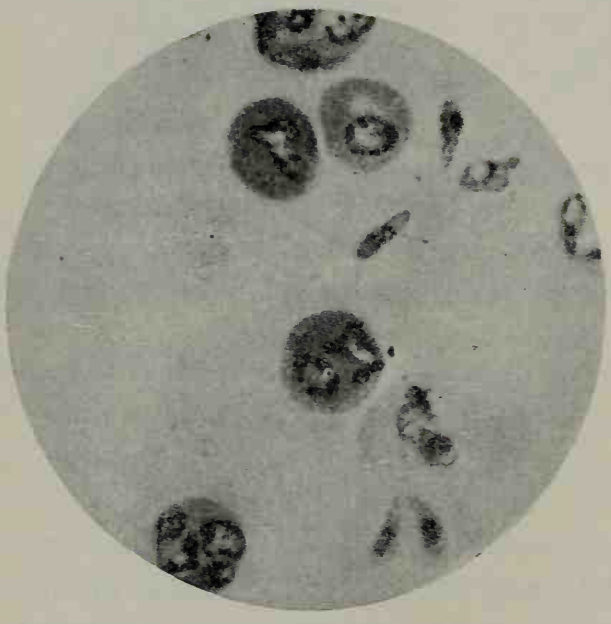

Fig. 140.—Piroplasma canis in blood of a dog (Nuttall and Graham Smith).

Nuttall and Graham Smith* have made an exhaustive laboratory study of this disease and have described with great wealth of detail that part of the life-cycle of Pir. canis which is passed in the blood of the dog. According to these investigators, the development takes place in the following manner:

A free pyriform parasite enters a normal red blood-corpuscle and rapidly assumes a rounded form. It then enlarges and passes

* Nuttall and Smith: Jour. of Hygiene, 1904, 4, p. 219; 1905, 5, p. 237; 1905, 5, p. 250; 1906, 6, p. 586; 1907, 7, p. 232. See also Kinoshita: Arch. Protistk., 1907, 8, p. 294; Christophers: Sci. Memoirs, Med. and Sanit. Dept., Govt. of India, No. 29, 1907; Breinl and Hindl; Ann. Trop. Med., 1908, 2, p. 233.

through an actively ameboid stage, at the end of which it again becomes rounded. After a short period of quiescence in this condition it protrudes two symmetrical processes, which rapidly grow and become pear-shaped. The protoplasm of the parasite flows into these processes, and its body consequently gradually diminishes until it is represented by a minute rounded mass to which the pyriform processes are attached. Eventually this also disappears, and finally two mature pyriform parasites are left, which are joined together for a time by a thin strand of protoplasm. After a variable time these parasites are liberated by the rupture of the corpuscles, and swim away to enter fresh corpuscles and repeat the process (Fig. 140).

Kleine* and Miyajima† report successful cultivation experiments with this parasite (Kleine) and with Pir. parvum (Miyajima). Growth with developmental changes is said to have occurred in dog's blood and in blood broth. Flagellated forms differing widely from those found in the body of the host were observed by Miyajima.

Piroplasma equi.—A disease of horses especially studied by Theiler‡ in South Africa, and presenting many striking resemblances to the piroplasmosis of dogs, is apparently caused by a piroplasma specific for the horse. Inoculation experiments from one horse to another are successful, but by no means invariably so. In nature ticks are suspected, though not proved, to communicate the disease.

Piroplasma ovis.—A piroplasmosis of the sheep was first discovered in 1888 by Babes,§ although this investigator did not recognize the protozoan nature of the parasite. The disease is transmitted by a tick (*Rhipicephalus bursa*). Especially interesting is the fact that the larvæ and nymphæ raised from infected eggs are incapable of conveying the infection, although the mature ticks of the same brood are infective. In this respect the sheep piroplasmosis resembles that of the dog and differs from Texas fever.

* Zeit. f. Hyg., 1906, 54, p. 10.

† Phil. Jour. Sci., 1907, 2.

‡ Theiler: Schweizer Archiv f. Tierheilk., 1901, 43, p. 253; trans., Jour. Comp. Path. and Ther., 1902, 15, p. 40.

§ Babes: Compt. rend. Acad. Sci., 1892, 115, p. 359.

Other Pathogenic Protozoa

Among other pathogenic sporozoa may be mentioned **Coccidium cuniculi,** a very common parasite in rabbits, where it is found especially in the liver. In these animals it evokes cirrhotic changes and other chronic inflammatory processes. A few cases, apparently well authenticated, are on record of the transfer of this parasite to man. Several of the myxosporidia, a subdivision of the sporozoa, are definitely associated with the production of disease in fish, one of the best known of these cases being the pox disease of carp, caused by **Myxobolus cyprini.** The parasite causing the disease of silkworms known as pébrine, celebrated by Pasteur's classic researches, also belongs to this group (**Nosema bombycis**). Another subdivision of the sporozoa, the sarcosporidia, contains a number of parasites, most of which are characterized by their ability to invade muscle-fibers. A large variety of animals are subject to invasions of parasites of this class, and there are at least two well established instances of sarcosporidiosis in man.

The highest group of protozoa, the ciliate infusoria, contains relatively few parasites. Among the parasitic forms, a paramecium-like organism, **Balantidium coli,** is the only one to which a pathogenic effect upon man has been attributed.

This infusorium has been found in over one hundred cases, usually associated with diarrhea or dysentery. A considerable percentage of patients give a history of having eaten or prepared pork sausage or of having been more or less closely associated with the care of swine. The parasites are found in the intestinal walls, capillaries, and blood-vessels, as well as in the stools. Strong,* after description of a case and an exhaustive survey of the literature, concludes as follows: "Whether the Balantidium coli is capable of producing a primary erosion in the intestine has not been conclusively demonstrated. However, if such an erosion of the mucosa exists from any cause, the parasite is certainly capable of continuing the process and of modifying and producing, in connection with the bacteria which accompany it, more or less characteristic pathologic lesions."

* Strong: No. 26, Publications of Government Laboratories, Manila, December, 1904.

CHAPTER XXXI

THE BACTERIOLOGY OF MILK AND MILK PRODUCTS

It is a familiar observation that milk sours on standing. The agency of bacteria in this, one of the earliest known fermentive processes, was established by the work of Pasteur in 1857. It was first shown by Hueppe in 1884 that a particular species of micro-organism was usually associated with the process.

The Fermentation of Milk.—The lactic fermentation consists in the conversion of milk sugar or lactose into lactic acid (Ger., *Milchsäure*). Lactose itself is not directly fermentable, but must first be converted into the simpler sugars, glucose and galactose. The equation,

$$\underset{\text{Lactose}}{C_{12}H_{22}O_{11}} + \underset{\text{Water}}{H_2O} = \underset{\text{Lactic Acid}}{4C_3H_6O_3}$$

although substantially correct, has only an approximate value.

The quantity of acid necessary to effect the curdling of milk (precipitation of the casein) varies somewhat according to the amount of casein and phosphate present, but averages about 0.45 per cent. The terminal acidity may go much higher than this (0.85 per cent.). Sometimes the coagulation of milk takes place in the presence of a relatively small amount of acid, especially if the milk is boiled or pasteurized. In general, the curdling of milk depends upon degree of acidity, temperature, time of action, amount and solubility of calcium salts present, and other factors. The heat generated in the spontaneous souring of milk is far greater than could come from the lactose fermentation alone; the process is, therefore, a complicated one.

Many different species of bacteria are able to provoke the lactic fermentation, among them such familiar organisms as Staphylococcus aureus, Streptococcus pyogenes, and B. coli. A few species are commonly responsible, however, for the natural souring of milk. The common lactic acid bacteria may be divided into two groups. One of these comprises capsulated gas-forming bacilli of the B. (lactis) aërogenes type. These organisms are closely related to B. coli,

differing principally in their possession of capsules, in their lack of motility, and their ability to produce gas from potato starch. (See p. 259.)

The second type is a streptococcus to which the name Streptococcus lacticus has been given (Kruse*) (Fig. 141). This streptococcus is very abundant in naturally soured milk, particularly when the acidity has reached a high point. Streptococcus lacticus has been found by Heinemann on the skin of cows, in cow-dung, and in milk at all stages of handling. The milk streptococcus in all its properties is extraordinarily like Streptococcus pyogenes (Heinemann†).

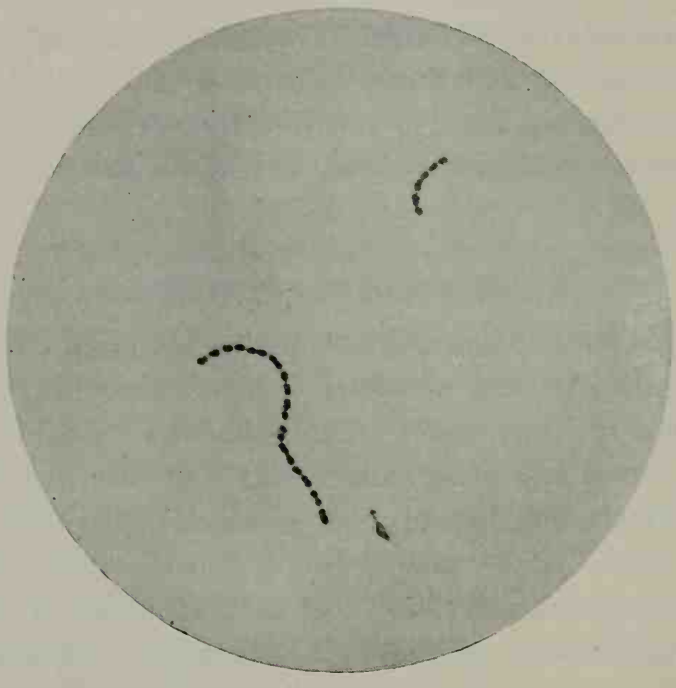

Fig. 141.—Streptococcus lacticus from serum broth (Heinemann).

As the result of a comprehensive investigation Heinemann concludes that both B. aërogenes and Streptococcus lacticus are ordinarily present in naturally souring milk, the former species in abundance in the beginning of the fermentation, the latter in the later stages. Inoculation of sterilized milk with pure cultures of these

* Leichmann ("Milchzeit," 1899, 23, p. 523) was the first to demonstrate the importance of this group of organisms, although he erroneously regarded them as bacilli, and gave them a name (Bacillus lactici acidi) which has been the source of much confusion.

† Heinemann: Jour. Infect. Dis., 3, 1906, p. 173.

two organisms and with mixtures reproduces very closely the process of natural souring.

Although milk allowed to stand ordinarily turns sour from the formation of lactic acid, other fermentations are exceptionally observed. The butyric acid fermentation

$$C_6H_{12}O_6 = \underset{\text{Hydrogen}}{2H_2} + \underset{\text{Carbon Dioxid}}{2CO_2} + \underset{\text{Butyric Acid}}{C_4H_8O_2}*$$

is one of the most thoroughly studied, and can be caused by a number of different, but closely related, anaërobic bacteria. Several well-known pathogenic anaërobes, such as the bacillus of symptomatic anthrax and of malignant edema, are able to produce butyric acid. Schattenfroh and Grassberger,† who have made a particular study of this fermentation, describe also a "motile butyric acid bacillus" which, like the two non-motile forms above mentioned (non-motile butyric acid bacilli), is widely distributed in nature, but, unlike them, is not pathogenic. A distinction is also made between those bacteria that are able to produce butyric acid from carbohydrates (and to some extent from lactic acid and glycerin) and those that produce butyric acid accompanied by the generation of malodorous gases in the course of protein decomposition. To the former class belong the anaërobes already mentioned; to the latter, certain aërobes closely allied to the hay-bacillus or potato bacillus (*e. g.*, B. putrificus).

The spontaneous alcoholic fermentation of milk is less usual under natural conditions than either the lactic or butyric. The manufacture of certain alcoholic beverages is, however, dependent upon the artificial production of this form of milk fermentation. A well-known drink called koumiss is made by Tartars from mare's milk, a small quantity of old koumiss often being added to fresh milk as a starter. The bacteriology of the process is not known. The similar beverage known as kefir, an effervescent sour milk prepared by the inhabitants of the Caucasus from the milk of cows, goats, and sheep, is made with the aid of "kefir grains," small, irregular, yellowish granules of a gelatinous consistency. The microbic composition of the kefir grain has been studied by a number of in-

* The actual process is much more complex than indicated by this equation.

† Schattenfroh and Grassberger: Arch. f. Hyg., 1900, 37, p. 54.

vestigators, with rather discordant results.* Several species of bacteria have been described at present, but it does not seem probable that all the organisms found in kefir grains are necessarily concerned in the specific fermentation process. According to Nikolaiewa,† only two micro-organisms (Bacillus caucasicus and Torula kefir) are essential, and all the others are to be regarded as accidental contaminations. Bacillus caucasicus is a long, slender non-motile bacillus which produces great quantities of lactic acid from milk-sugar. The yeast-organism ferments lactose, glucose, and sucrose, and is apparently responsible for the alcoholic part of the fermentation. By the symbiotic use of these two species of micro-organisms in pure cultures Nikolaiewa succeeded in preparing the characteristic kefir beverage. In such processes, however, the action of bacteria is not always indispensable. Some species of yeasts are able to effect the alcoholic fermentation of milk in pure culture.

A variety of other fermentations of milk may be sometimes caused by bacteria. Casein may be precipitated by rennet of bacterial origin (Conn‡) or dissolved by bacterial casease. The behavior of pure cultures of various micro-organisms inoculated into sterilized milk gives evidence of widespread ability to provoke fermentation changes. Many cultures cause acid production and consequent precipitation of the casein, which is then slowly dissolved (casease); others dissolve the casein without initial precipitation, and still others curdle the milk without acidity (rennet).

A series of unusual or abnormal changes, sometimes called "diseases" of milk, are produced by certain bacteria which occasionally find their way into milk from uncleanly surroundings. "Blue milk" (B. cyanogenes), "red milk" (B. prodigiosus, B. erythrogenes, *et al.*), and "yellow milk" (B. synxanthus) are caused by the presence of various chromogenic organisms. The bitterness that sometimes develops in milk after a short interval is due to the products of certain micro-organisms. Several different bacteria have been met with in outbreaks of this not very uncommon dairy trouble. Harrison§

* Beijerinck: Centralbl. f. Bakt., 1889, 6, p. 44; v. Freudenreich: Landw. Jahrb. d. Schweiz, 1896, 10, p. 1.

† Centralbl. f. Bakt., ii, 1908, p. 161.

‡ Conn: Storrs Agri. Exp. Sta. Rep., 1892, 5, p. 196.

§ Harrison: Centralbl. f. Bakt., ii, 1902, 9, p. 206.

found that a yeast-like organism (Torula amara) was apparently the active agent in an epidemic of bitter milk in Canada. There seems little doubt that a number of species are capable of imparting a bitter taste to milk and its products, although nothing is known of the chemical nature of the substances concerned. Milk sometimes suffers also from a ropy or slimy fermentation which, under most circumstances, is considered undesirable and has caused great loss to the butter industry in Switzerland and elsewhere. Thorough disinfection of the utensils and premises is usually sufficient to stamp out all these anomalous and in some instances disastrous fermentations. For certain purposes, as in the manufacture of Edam cheese in Holland, slimy milk is intentionally produced by use of a particular species of streptococcus.

Sources of Bacteria in Milk.—Freshly drawn milk is not sterile, but always contains some bacteria. Under ordinary conditions these come in part from the surface of the udder, from the hands of the milker, and other outside sources, but always in part also from the udder itself. After much conflicting testimony, it is now well established that the milk in the udder of the cow is rarely, if ever, germ-free, but that the germ-content is different in different animals, and that the first portion of the milk drawn (fore-milk) always contains more bacteria than the last (strippings). The milk secreted by healthy milk-glands is, as a rule, sterile, but the milk-ducts in the teats of the cow afford a ready pathway for the invasion of the udder. The bacteria that abound in the milk-ducts would probably grow back into the udder more freely than they do if it were not for the germicidal power possessed by milk, as by other body-fluids. The existence of a germicidal property has been called in question,* and the death of bacteria falling into milk ascribed simply to their inability to grow in that medium, but even those kinds best adapted for growth die off at first when introduced into perfectly fresh milk. Most investigators agree that milk, like serum, possesses a genuine although feeble germicidal power.† The action is different for different species of bacteria, and the milk from one animal may be more powerful than that from another. At best, the germicidal property can never be relied upon to take the place of cleanliness and icing.

* Stocking, Storrs Agri. Exp. Sta. Rep., 1904.

† Rosenau and McCoy: Jour. Med. Res., 1908, 18, p. 165.

When milk is collected under ordinary conditions, the udder germs form but an insignificant fraction of the total number of bacteria in the milk. The skin of the cow, the hands of the milker, the vessels used for collection, and the dust of the cowbarn all contribute their quota to the number found immediately after milking. If milk is obtained with aseptic precautions, it contains only a few hundred (200 to 400) germs in a cubic centimeter. Collected with somewhat less care, it may contain a few thousand (2000 to 6000); with careless manipulation milk, even when freshly drawn, may be highly contaminated (30,000 to 100,000). Milk is a particularly favorable medium for bacterial growth, and when it is richly seeded at the outset, enormous multiplication will occur, provided it is kept at ordinary summer temperatures. The temperature factor is indeed all-important. If milk is kept at 0° C. (32° F.), it shows a decrease in the bacterial content during the first one hundred and sixty-eight hours, but at higher temperatures the rate of multiplication is prodigious.

TABLE I.*

MILK COLLECTED WITH GREAT CARE.†

	KEPT AT:			
	4° C.	6° C.	13° C.	20° C.
24 hrs.	2,500	3,100	18,800	450,000
48 "	3,600	12,000	3,400,000	....
96 "	218,000	1,480,000	....	....
168 "	4,209,000	80,000,000	....	....

ORDINARY MILK.‡

	KEPT AT:			
	4° C.	6° C.	13° C.	20° C.
24 hrs.	38,000	42,000	187,000	4,000,000
48 "	56,000	360,000	38,000,000	....
96 "	4,300,000	12,200,000	....	....
168 "	38,000,000	300,000,000	....	....

* Adapted from Park, "Pathogenic Bacteria," N. Y., 1905, p. 463.

† Initial content, 3000. ‡ Initial content, 30,000.

Many such figures might be cited, but they all lead to the same conclusion: namely, that the number of bacteria in milk depends chiefly—(1) upon the degree of original contamination of the milk, (2) upon the age of the milk, and (3) upon the temperature at which it has been kept. In other words, the bacterial count gives valuable information both as to the cleanliness and staleness of this indispensable food. All observations emphasize the importance of rapidly chilling the milk as soon as possible after it is drawn, and of keeping it constantly at as low a temperature as possible. Milk collected in clean vessels with proper precautions, and then cooled and kept cool, has been preserved in a thoroughly sweet and fresh state for periods that seem surprisingly long judged by ordinary household experience. Bottles of such clean and cool milk, without addition of any preservatives, have been transported from the vicinity of Chicago to Europe without losing either palatability or wholesomeness.

Top-milk often contains from 10 to 500 times as many bacteria as the mixed milk. Centrifugally raised cream contains more bacteria per cubic centimeter than gravity raised cream from the same milk. The large number of bacteria in cream and top-milk may explain why infants sometimes do not thrive on modified milk made from top-milk.*

It is a matter of common knowledge that much of the milk distributed in large cities is too far advanced in bacterial decomposition to be a desirable food. In New York city it was found by Park† that during the coldest weather the milk in the shops averages over 300,000 bacteria per cubic centimeter; during cool weather, about 1,000,000, and during hot weather, about 5,000,000. In Chicago Heinemann and the writer‡ found in market milk collected during April, May, and June, numbers ranging from 10,000 to 74,000,000; and in Boston, Sedgwick and Batchelder§ reported that samples of milk from groceries averaged over 4,500,000.

* Anderson: Jour. Infect. Dis., 1909, 6, p. 392.

† Park: Jour. Hyg., 1901, 1, p. 391.

‡ Report of the Civic Federation of Chicago, 1904.

§ Sedgwick and Batchelder: Bost. Med. and Surg. Jour., 1892, 126, p. 25. This paper is the first report made upon the bacterial content of milk in an American city.

It cannot be pointed out too frequently that this excessive bacterial contamination is unnecessary, and that it can in large part be prevented by attention to simple details of cleanliness, involving almost no increase in expense. In several large cities milk collected and handled in such a way as to be "certified" or recommended by physicians for infant feeding is found to contain very few bacteria. The requirements of the New York Milk Commission specify that certified milk shall contain not more than 30,000 bacteria per cubic centimeter, and those of the Philadelphia Milk Commission that it shall have not more than 10,000. Little difficulty has been found in conforming to this standard. The city of Boston* has established a limit of 500,000, and the city of Milwaukee, 250,000. In still smaller communities it is possible to reduce the bacterial content of milk far below these figures. Montclair, N. J., has for some years waged war successfully against stale and dirty milk. In 1906 more than half of the dairies supplying the town furnished milk with an average bacterial content of less than 100,000. Rochester, N. Y., under the leadership of Goler, has established a bacterial limit of 100,000.

The question has often been raised whether there are not certain kinds of bacteria that invariably predominate in milk; whether, in short, it is not desirable to recognize the existence of a special class of milk bacteria. Swithinbank and Newman† give descriptions of some one hundred and twenty "milk bacteria," the statement being expressly made that "organisms of water, soil, etc., are not included." Other writers also appear to believe that certain species are especially adapted for life in milk, and habitually gain the upper hand in this fluid under natural conditions. As a matter of fact, there is little to recommend this view. Fresh milk is an admirable medium for the growth of a great many species of bacteria, as

* Article 51, Sec. 1. "No person by himself, or by his servant or agent or any other person, firm or corporation, shall in the City of Boston sell, exchange or deliver, or have in his custody or possession with intent to sell, exchange or deliver, any milk, skimmed milk, or cream which contains more than 500,000 bacteria per cubic centimeter, or which has a temperature higher than 50 degrees Fahrenheit." (Reg. for the Sale and Care of Milk, Boston Board of Health.)

† Swithinbank and Newman: "Bacteriology of Milk," New York, 1903, pp. 392–451.

reference to lists of "milk bacteria" will show, and there is no reason to consider it as preëminently favorable for a few special kinds. If some varieties are found in milk more commonly than others, this is in large part, if not altogether, because they are more commonly present in the environment in which the milk is collected. The dependence of the flora of milk upon the bacterial environment has been noted by many observers. The dust of the cow-stable, the nature of the straw used for bedding, even the character of the pasture, have been observed to affect the kind and abundance of the species found in milk. Weigmann and Zien* have shown that the use for bedding of a poor quality of straw, which is almost always full of molds—so-called wild yeasts—and peptonizing bacteria, is likely to be followed by undesirable fermentations in milk. On the whole, it would seem that the kinds of bacteria found in milk are more likely to be determined by the opportunities of contamination to which the milk is exposed, and the temperature at which it is kept, than by any special adaptability to this particular food medium.

The occurrence of pathogenic bacteria in milk is by no means unknown. Both individual cases and epidemics of several infectious diseases have been clearly traced to the drinking of milk. Two ordinary sources of infection are recognized: the germs may be derived directly from the cow, or they may be introduced into milk with infectious material of human origin. The latter is the much more common source. The bacteria of typhoid fever, of cholera, and of diphtheria, and probably the yet undiscovered germ of scarlatina, often find their way into milk through the agency of convalescents or by persons suffering from mild attacks of these diseases who are engaged in the milking process, or in the handling of milk and milk products.† Sometimes, too, infections may come about in a more circuitous fashion, as in the often exemplified instance of the causation of typhoid fever by the use of typhoid-infected water for rinsing milk-cans or other utensils. A serious source of danger lies in the improper disposition of excreta and in the fact that flies may convey typhoid bacilli from infected vaults to

* Weigmann and Zien: Milchzeit, 1893, 22, p. 569.

† See "Milk and Its Relation to the Public Health," Bull. 41, Hyg. Lab., Pub. Health and Mar. Hosp. Service, 1908, pp. 19–159.

milk. These possibilities have been elsewhere set forth in connection with the discussion of special diseases.

Tuberculosis attributed to milk is commonly assumed to be due to bacilli of bovine origin, but it is also possible for milk to become infected with tubercle bacilli from tuberculous persons. It is a not unknown practice in country districts for milkmen to begin the milking process by moistening their hands with saliva. Milk may also conceivably become contaminated with human tubercle bacilli by means of the "infectious droplets" discharged in coughing or sneezing. Owing to the difficulty of tracing a case of tuberculosis to its origin, the degree of danger from this source is uncertain, although the possibility of infection through tuberculous milkers should not be overlooked. The relation of bovine tuberculosis to human tuberculosis is elsewhere considered (pp. 353–355).

Among the diseases of the cow transmissible to man through the medium of milk, perhaps the first place should be given to foot-and-mouth disease (p. 565). Extensive outbreaks of this affection, which attacks especially infants and children, have been caused by the use of raw milk. In fact, milk, butter, and cheese are the usual, if not the exclusive, vehicles of the malady. Foot-and-mouth disease has been eradicated from the United States.

Inflammation of the udder of cows (garget or mastitis), a condition that may be provoked by a variety of organisms, is apparently fraught with some danger to the consumer of milk. On more than one occasion the use of milk from udder-sick cows has been followed by illness, but the bacteriology of these cases has not been determined. The same must be said of the association of enteritis in cows with gastro-intestinal troubles in man. The epidemiologic connection between sudden attacks of illness and the use of the milk of cows suffering from diarrhea is undoubtedly clear, but the nature of the micro-organisms (or toxins?) concerned is wholly obscure. Streptococci have been regarded as the cause of some of these outbreaks, organisms resembling B. coli of others; it is probable that one and the same species of micro-organism is not responsible for all cases.*

* The presence of streptococci and leukocytes in milk has been regarded by some writers as of considerable sanitary significance. The work of Kruse,

Some other affections to which cattle are liable seem of less importance. Actinomycosis attacks the cow's udder not infrequently, but not a single case of this disease in man has ever been shown to be communicated by milk. Anthrax likewise is not ordinarily and directly a milk-borne disease, probably in part, at least, because anthrax bacilli are able to pass from the circulation into the milk of an infected animal only in the later and easily recognizable stages of the disease. It is not known that rabies or the pleuro-pneumonia of cattle has ever been conveyed to man by milk, although if injuries of the mouth or digestive tract exist, rabic infection by this channel is theoretically conceivable. Goat's milk has been shown to be the chief medium of infection in Malta fever. (See p. 210.) In view of all these manifold, if not yet clearly understood, possibilities of infection, it would seem an indispensable precaution to avoid the use of uncooked milk from an animal with any symptom of illness whatever.

Infantile Diarrhea.—The occurrence of "infantile" or "summer" diarrhea in young children whose food consists wholly or in large part of cow's milk has been the subject of much investigation. The predominant influence of feeding upon this condition is shown by numerous comparisons that have been made between the sickness and mortality among breast-fed children and that among those fed

Hölling, Heinemann (Jour. Infect. Dis., 1906, 3, p. 173) and others has shown that streptococci may be present in milk collected from healthy animals and under cleanly conditions, and that the number of streptococci increases on standing. Undoubtedly pathogenic streptococci are sometimes present in milk drawn from inflamed udders, but at present there seems no sure method of differentiating these from the streptococci found in great abundance in clean sour milk.

The presence of leukocytes in milk has also given rise to widely diverse opinions. Harris (Jour. Infect. Dis., Suppl. No. 3, 1907, p. 50) concludes that "the sanitary significance of the so-called 'pus-cell' has been greatly overrated. More scientific attention should be given to the study of the phenomena of lactic leukocytosis, together with a more accurate method of enumeration, such as that of Doane and Buckley or of Savage." Russell and Hoffmann (Ibid., p. 65) have come to substantially the same conclusion. On the other hand, Pennington and Roberts (Jour. Infect. Dis., 1908, 5, p. 72) are inclined to attach considerable significance to the occurrence of streptococci and leukocytes in milk as an index to specific udder affection and to systemic disturbance.

with condensed milk or cow's milk. The following figures (from Park) are typical of the difference observed everywhere:

	Did Well.	Did Fairly.	Did Badly.	Died.	Total.
Store milk.....	21	23	20	15	79
Condensed milk.....	22	20	14	14	70
Best bottled milk	9	3	0	0	12
Breast feeding.....	17	7	7	0	31

In Berlin, Germany, during the five years, 1900–1904, there were 41,383 deaths of infants whose method of feeding was ascertained; only 3995 of these were breast-fed; in other words, more than nine-tenths of the infant mortality occurred among those fed artificially. Harrington* has pointed out that infantile mortality is a class mortality, highest, as a rule, in those cities and towns where women work in industrial establishments and put their children early to the bottle.

The bacteriology of infantile diarrhea is itself by no means definitely established. Some observers would lay the responsibility at the door of certain streptococci very similar to, if not identical with, Streptococcus pyogenes, but this view has not met with general acceptance. More recently, varieties of the dysentery bacillus have been connected with summer diarrhea, and have been found in large numbers and repeatedly by a number of observers in the stools of typical cases.† It is not necessary to assume, however, that identical clinical symptoms are invariably caused by one and the same micro-organism. Booker,‡ one of the most indefatigable workers in this field, has expressed the opinion that "no single micro-organism is found to be the specific exciter of the summer diarrhea of infants, but the affection is generally to be attributed to the result of the activity of a number of varieties of bacteria." Park and Holt, as the result of a comprehensive study of the relation between milk-supply and infantile diarrhea in New York city, reached the conclusion that "no special varieties of bacteria were found in unheated milk which seemed to have any special importance

* Harrington: Amer. Jour. Med. Sci., 1906, 132, p. 811.

† Studies from the Rockefeller Inst. for Medical Research, 2, 1904.

‡ Booker: Johns Hopkins Hosp. Rep., 1896, 6, p. 253.

in relation to the summer diarrhea of children."* While it is therefore perhaps premature to assign a uniform bacterial cause for every case of infantile diarrhea or to attempt to differentiate between different causes, there can be no doubt as to the influence of the numbers of bacteria in milk. The most conclusive investigations on this point are those of Park and Holt. These observers found that during hot weather the effect of bacterial contamination on the health of infants was very marked when milk was fed without previous heating. "When milk is taken raw, the fewer the bacteria present the better the results. Of the usual varieties, over 1,000,000 bacteria per cubic centimeter are certainly deleterious to the average infant."

It should be remembered that when once the specific agent of intestinal trouble, whatever it be, is introduced into the gastro-intestinal canal of infants, the continued use of milk from any source is injurious. If the resistance of an infant is depressed by hot weather, the effect of abnormal fermentation and putrefaction of the milk within the body may be especially serious. The factors involved in the causation of summer diarrhea in infants are varied and complex.

Pasteurization.—As already indicated, the number of bacteria in raw milk can be largely controlled by reasonable attention to cleanliness and cooling. Even in large cities it is possible to supply clean fresh milk without appreciable additional cost to the consumer. The sale of milk containing more than 500,000 bacteria per cubic centimeter should not be permitted. Pending the establishment of this general standard of bacterial purity, other measures for overcoming the danger from excessive bacterial contamination are frequently resorted to. One of the most efficacious of these is the process of pasteurization. Originally devised by Pasteur for preserving wines without loss of their original flavor or bouquet, it has come to be widely used for the treatment of milk. Milk that is pasteurized by heating to 60° C. for twenty minutes is less altered from its original constitution than boiled or "sterilized" milk, and is probably more readily assimilated by the child. The following table, from Park and Holt, shows the beneficial effect of the use of pasteurized milk:

* Park and Holt: Archives of Pediatrics, Dec., 1903, 20, p. 881.

Kind of Milk.	Number of Infants.	Remained Well for Entire Summer.	Number having Severe or Moderate Diarrhea.	Average Number Days off Milk During Summer.	Average Weekly Gain in Weight.	Average Number of Days Diarrhea.	Deaths.
Pasteurized milk, 1,000 to 50,000 bacteria per c.c.	41	31	10	3	4.0 oz.	3.9	1
Raw milk, 1,200,000 to 20,000,000 bacteria per c.c.	51	17	33	5.5	3.5 "	11.5	2

Thirteen of the fifty-one infants on raw milk were transferred before the end of the trial to pasteurized milk because of serious illness. If these infants had been left on raw milk, it is believed by the writers that the comparative results would have been even more unfavorable to raw milk.

When the infants in the care of the city of New York (Randall's Island) were fed on milk from a carefully selected herd pastured on the island, the death-rate was as follows:

Year.	Children Treated.	Number of Deaths.	Percentage.
1895	1216	511	42.02
1896	1212	474	39.11
1897	1181	524	44.36
Total	3609	1509	41.81

A pasteurizing plant was installed in the early part of 1898. No other change in diet or hygiene was made.

Year.	Children Treated.	Number of Deaths.	Percentage.
1898	1284	255	19.80
1899	1097	269	24.54
1900	1084	300	27.68
1901	1028	186	18.09
1902	820	181	22.07
1903	542	101	18.63
1904	345	57	16.52
Total	6200	1349	21.75

Had the ratio of deaths for the three years, 1895, 1896, and 1897, been maintained in the seven years from 1898 to 1904, the total infant mortality would have been 2592, instead of 1349, a difference of 1243.*

The striking difference in favor of pasteurized milk shown by these figures probably obtains only in the case of milk of average quality. If milk before pasteurization contains many millions of bacteria, heating will not remove entirely its deleterious qualities. The observations of the New York Milk Commission indicate that pasteurization of dirty milk is a questionable proceeding and may be followed by harmful results. It must be remembered, however, that in any case pasteurization greatly diminishes, if it does not altogether prevent, the likelihood of specific infection. The bacilli of typhoid fever, dysentery, diphtheria, and tuberculosis are killed at the temperature of pasteurization, and this constitutes a strong argument for the process.

Although there is not at present entire unanimity of opinion among sanitarians regarding the relative merits of pasteurized milk and raw milk, it must be admitted that a strong belief in the advantage of pasteurization is growing up. Objections to pasteurized milk on the ground that it favors the development of scurvy and rickets have been shown to be unfounded; the enzymes in raw milk to which some writers have attached nutritional importance are not destroyed by exposure to a temperature of 60° C. for twenty minutes; the argument that pasteurization conceals the presence of dirt is open to the retort† that since the bacteria that come from dirt are largely resistant spore-forming varieties, it may be possible, after the ordinary lactic acid bacteria have been killed off by heating, to determine bacteriologically the presence of dirt in pasteurized milk more readily than in raw milk. Finally, it must be again emphasized that one important advantage of pasteurization is that it removes the danger of transmission of specific disease germs—a danger by no means absent even when milk is collected from healthy cows and in clean stables. The liability of certain healthy persons, the "disease-germ carriers," to infect their surroundings has been elsewhere discussed (p. 126), and may readily be seen to be of especial

* Bull. No. 41, Hyg. Lab., Pub. Health and Mar. Hosp., 1908, p. 237.

† Smith, Theobald: Amer. Jour. Pub. Health, 1907, 17, p. 200.

importance in connection with the handling of milk. It is difficult to guard against infection from this source, but the process of pasteurization does much to minimize the danger.

The commercial pasteurization of milk in large cities should be under the direct supervision of the health authorities, and should be carried out with proper regard to prompt chilling of the milk after heating, as well as to protection against subsequent contamination, and to quick delivery.

Milk Products.—*Butter.*—The share of bacteria in the processes involved in the manufacture of butter and cheese is important, although at present imperfectly understood. In the making of butter the proper ripening of the cream has long been recognized as essential to the production of a desirable flavor and aroma. Butter made from sweet cream is insipid, and lacks the pleasant taste of sour cream butter. On the other hand, if the ripening process be continued too long,—for example, for six days, instead of two,—undesirable fermentations may set in which injure the butter hopelessly. In other words, the products of some bacteria appear pleasant and aromatic to the average person, while the products of other bacteria are objectionable or even strongly offensive. Butter sometimes has a bitter, fishy, soapy, oily, or "turnip" taste, which completely destroys its palatability. Different species of bacteria have been reported as occurring in association with these various kinds of "bad" butter. Members of the Bacillus coli group, for example, have been found in connection with the occurrence of the turnip taste. It is not yet certain to what extent the rancidity of butter is due to bacteria. The access of light and air certainly favors the development of the products —free acids—that give a rancid taste, but the influence of air seems to be indirect. That is, the presence of oxygen favors the multiplication of those aërobic bacteria which are able to split up the butter-fats. The action of light seems to be one of direct oxidation of the fatty acids. The becoming rancid of oleomargarine has been ascribed to the activity of two special kinds of bacteria.

When the manufacture of butter is carried on in a dairy or creamery under ordinary hit-or-miss conditions, it is largely chance that determines what kinds of bacteria take part in the

ripening process. Some dairies happen to contain varieties of bacteria which have become naturally domesticated in the surroundings and produce palatable compounds, while others are infested with species that impart a bitter or tainted flavor to the ripened cream. For these reasons many attempts have been made to control the ripening process. Storch in Denmark, Weigmann in Germany, and Conn and Russell in the United States have been foremost in applying to butter-making the use of pure cultures of favorable germs.

Before the use of pure cultures it had been the custom in many successful dairies to use a "starter"; that is, a small quantity of cream that had shown the looked-for qualities in ripening. This was added to fresh cream, the obvious if unconscious purpose of this proceeding being to impregnate the fresh cream with the specific organism or organisms present in the starter. Examination of the "natural starters" has shown that they are mixtures of several different organisms, but that bacteria able to produce lactic acid greatly preponderate (95 per cent.). The next step toward putting butter-making on a scientific basis was to remove the uncertainty due to the use of mixed cultures, and different investigators soon isolated micro-organisms which were able, especially under carefully controlled conditions, to imbue butter with an agreeable aromatic taste and odor. Over a score of such artificial starters are now said to be in use in various parts of the world. At the present time inoculation with pure cultures after preliminary pasteurization of the cream is practised chiefly in Denmark; in the United States the procedure has not won very extensive acceptance, partly, it is said, because the public taste in this country demands a butter with a rather strong flavor.

The nature and interrelationship of the several cultures used for cream-ripening is not altogether clear. All seem to be lactic acid bacteria; some are streptococci, apparently identical with Streptococcus lacticus (Heinemann). The difference in ability to produce desirable flavor is in many cases undoubtedly a racial or varietal rather than a specific difference, organisms otherwise closely allied differing in this respect. It seems important in all cases to control the conditions of ripening (*e. g.*, to maintain a temperature

of 60° to 75° F.) if the best results with artificial starters are to be obtained. Especially advantageous is the preliminary pasteurization of the cream, which eliminates most of the bacteria that might interfere with the free development of the organism added in the starter. Clean utensils and surroundings are quite indispensable to the successful use of an artificial starter (pure cultures) and the output of a product of uniform quality. In short, the manufacture of butter is tending to become essentially a bacteriologic process dependent upon the action of particular bacterial species and upon the conditions that surround their growth.

Cheese.—The bacteriology of cheese-making is, generally speaking, on a more indefinite footing than that of butter-making. Some of the flavors characteristic of the different varieties of cheese are without doubt due to bacteria and molds, but the precise nature of the species concerned, and the conditions of their action, are in most cases largely a matter of conjecture. The casein or curd of milk, when freshly precipitated, usually by the addition of rennet, is insoluble; but a process of ripening ensues during which it is converted into soluble bodies. The digestion of the casein is effected principally through the agency of bacteria, but possibly in part also by enzymes in the milk (galactase, Babcock and Russell). Two types of cheese, the "hard" and the "soft," are made from ripened curd,* the difference being primarily due to a difference in the mechanical treatment of the curd. The milk for the hard cheeses is curdled rapidly, and much of the whey is separated from the curd by heating, manipulation, and pressure. For soft cheeses the whey is never thoroughly drained from the curd. The difference in consistency brings about difference in rapidity of ripening and in the amount of bacterial action. The soft cheeses (Brie, Camembert, Gorgonzola, *et al.*) are ready for the table much sooner than the others, and are also more perishable. The flavor and odor of these cheeses are often strong and sometimes offensive, as in the case of the classic Limburger. In the ripening of certain varieties of the soft cheeses, only bacteria are thought to be concerned; in others, molds growing on the exterior contribute to the ripening (Brie,

* The so-called cottage cheese and the cheese sold in the United States under the name of Neufchâtel are merely unripened curd.

Camembert), and in still others molds permeate the whole curd, and are, perhaps, the main agents (Roquefort, Gorgonzola, Stilton). Some advance has recently been made in determining the species of micro-organisms that take part in the production of certain cheeses. The ripening of Camembert cheese, for example, has been carefully studied by Conn and his collaborators,* who conclude that two kinds of molds are necessary for the proper ripening and for the development of the characteristic flavor (Fig. 142). One of these is a species of white mold (Penicillium candidum?) closely

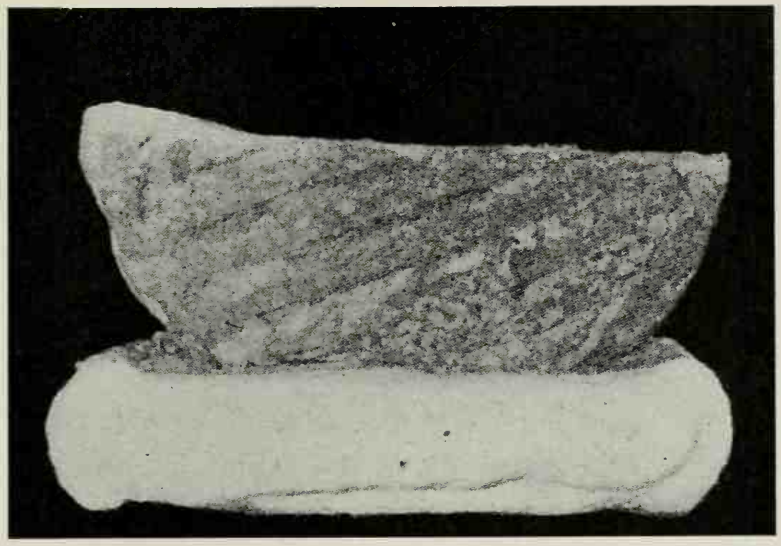

Fig. 142.—Camembert cheese cut open to show the softening of the curd (Conn).

allied to the common blue-green mold (Penicillium glaucum). This mold is not found in ordinary milk, and, in fact, for a long time one of the main obstacles to the manufacture of Camembert cheese in the United States was the failure to obtain and control this organism.

The texture of Camembert cheese seems to be due primarily to the growth of the species in question. Other species of Penicillium either fail to soften the curd characteristically or else impart to it an unpleasant bitter taste. The Camembert Penicillium (Fig. 143) forms a felted mass on the surface, penetrating perhaps $\frac{1}{16}$ of an inch into the curd. The spores of the mold usually ripen during the third week, and no further change takes place. "A cheese ripened by this mold alone is white, soft, creamy, and entirely palat-

* Bull. 35, Storrs Agr. Expt. Station, 1905.

able, but is wanting in color, and completely lacks the peculiar flavor for which Camembert cheese is sought in the markets."

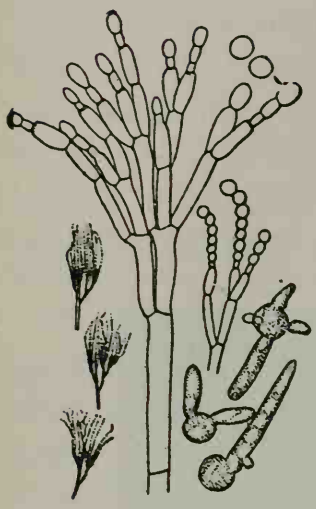

Fig. 143.—Penicillium of Camembert cheese, showing method of forming spores (Thom).

The Camembert *flavor* is due mostly, perhaps wholly, to the well-known and widely distributed mold or yeast-like organism, Oïdium lactis (Fig. 144). Much seems to depend upon maintaining a proper balance between the Penicillium and the Oïdium. A final conclusion as to whether or not Oïdium lactis alone produces the flavor will depend upon an exhaustive test of those bacteria so constantly associated with it.

Other cheeses derive their characteristic qualities from the proportion of various micro-organisms. In certain Swiss and Belgian soft cheeses the principal share in ripening is attributed to Oïdium lactis (Freudenreich and Marchal). The famous Roquefort cheese owes its characteristics, at least in part, to a Penicillium (P. glaucum?) which grows at the low temperature prevailing in the limestone caverns common in that district in

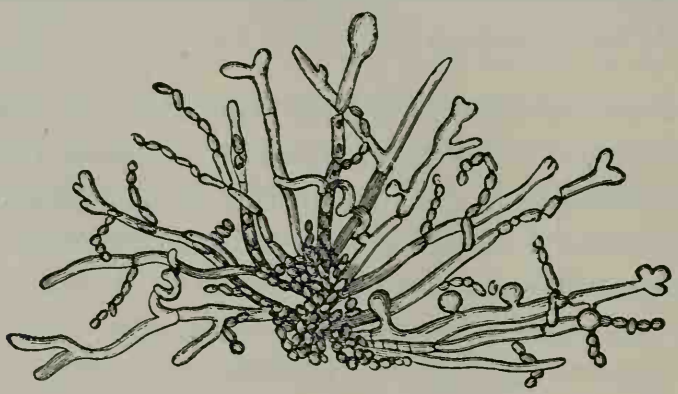

Fig. 144.—Oïdium lactis colony on gelatin (Conn).

France which gives its name to the cheese. Various kinds of Penicillium, perhaps all to be regarded as varieties of Penicillium glaucum, are particularly active in cheese ripening. They not only exert a proteolytic action themselves, but by their destruction and alteration of the acid products facilitate the action of

the peptonizing bacteria. They also influence the flavor of the cheese. The sharp taste of such cheese as the English Stilton, the French Roquefort, and the Italian Gorgonzola and Parmesan cheeses is due to the products of these molds. The hard cheeses (Cheddar, Swiss, American, Edam, and others) are thought to be ripened exclusively by bacteria without intervention of molds. Edam cheese is made with slimy whey as an artificial starter; this contains a streptococcus (Str. Hollandicus).

The number of bacteria present depends to a large extent upon the age of the cheese. Both hard and soft cheese may contain enormous numbers, especially in the first days after preparation. Cheddar cheese, for example, has been found to contain as many as 635,000,000 bacteria per gram. After an apparently somewhat variable period of increase, a diminution sets in, and the numbers at first rapidly, then more slowly, decrease. In old cheese as few as 1400 germs per gram have been found. The increase of the first two weeks is thought to be due principally to the lactic acid bacteria. At first, however, this group of bacteria shows a slight decrease, owing apparently to the fact that the peptonizing bacteria then have the upper hand (Russell and Weinzirl). Some difference of opinion has existed regarding the relative share of the peptonizing and lactic acid bacteria in the normal ripening process. The view especially advocated by E. von Freudenreich that the lactic acid bacteria are primarily concerned in the ripening of cheese has met with some opposition. Many investigators believe that the peptonization of the curd by aërobic, casein-dissolving bacilli of the Bacillus subtilis group—the Tyrothrix bacteria of Duclaux—or by casease-producing cocci (Weigmann) is to be regarded as the essential feature of the ripening of cheese. On the other hand, most investigators are agreed that the acid reaction brought about by the lactic acid bacteria is requisite to a normal ripening. Were it not for the restraining influence of the acid, the peptonizing bacteria would carry on their activities to the stage of putrefaction.

The ripening of cheese may, therefore, be considered as a process in which different groups of bacteria participate, one species after another gaining the upper hand (metabiosis). The lactic fermentation organisms are particularly important, since various

decomposition processes are checked by their products. It has been urged by some investigators (Rodella) that anaërobic bacilli are intimately connected with the ripening of many varieties of cheese, and there is some evidence for this view.

The use of pasteurized milk inoculated with pure cultures or selected mixed cultures of micro-organisms has in some cases given rise to a normal ripened product, but in others has been unsuccessful. The complicated nature of cheese-ripening, which seems to depend upon the successive activity of different groups of bacteria as well as upon the presence at the right time of suitable aroma-producing species, renders the bacterial control of cheese manufacture particularly difficult.

Both butter and cheese are liable to "abnormal" ripenings or fermentations which impair the palatability and other marketable qualities. Bitterness has been attributed to the products of various micro-organisms, such as Oïdium lactis, Bacillus fluorescens liquefaciens, and others. Sometimes genuine putrefactive changes are observed. Hard cheese is not uncommonly spoiled by the growth of gas-producing bacteria, which cause the formation of numerous cavities in the substance of the cheese. The "spongy" or inflated cheeses usually acquire also an unpleasant flavor. The bacteria concerned belong to the lactic group (Russell), and are perhaps to be identified with Bacillus aërogenes. The formation of the cavities is best prevented by carrying on the ripening at a temperature so low that the gas-producing organisms do not thrive. "Tainted" and "bitter" cheeses, as well as cheeses spotted or patched with color (chromogenic bacteria), are also reported from time to time. The rusty spots on American cheddar cheese are due to a chromogenic bacillus named Bacillus rudensis.* This organism seems to find especially favorable conditions for its growth in spring and early summer, and, although it does not seem to injure the taste of the cheeses on which it grows, it does affect their marketability. The remedy for the nauseous or unpalatable fermentations of cheese and butter lies in a more scrupulous attention to cleanliness in the surroundings of factory and dairy, and generally in a more rigorous bacteriologic control.

* Harding, Rogers and Smith: Bull. No. 183, N. Y. Agr. Expt. Sta., 1900.

Infection from Butter and Cheese.—Pathogenic bacteria which occur in milk may, of course, sometimes find their way into the milk-products. Butter and cheese made from the milk of animals suffering from foot-and-mouth diseases are known to have produced infections (Ebstein,* Thiele†). Tubercle bacilli (of bovine origin?) have been found in butter by a number of observers. One of the most recent tabulations of such investigations‡ shows that in seven hundred and twenty-seven samples tested, mainly the market butter in German cities, tubercle bacilli were found in eighty-eight samples, or about 12 per cent. Tubercle bacilli have also been reported in the quick-ripening varieties of cheese by Rabinovitsch,§ Harrison,‖ and others. As pointed out in the chapter on tuberculosis (p. 353), the significance of such findings for public health is quite problematic. It is by no means impossible for milk and milk products to be infected with tubercle bacilli of human origin. The discharge of tubercle bacilli by a tuberculous milkman, for example, in the act of sneezing and in other ways opens up many chances for infection. It needs no argument to show that the employment of tuberculous persons in the dairy is fraught with more or less peril to the community.

Many experiments have been made to determine the longevity of the typhoid bacillus in butter and cheese. The results are quite conflicting, but seem, on the whole, to show a survival period of only a few days, especially where souring of the milk or cream has taken place. No case of typhoid fever has ever been definitely traced to the use of infected butter, but the epidemiologic evidence for such a source of infection would evidently be very difficult to secure. The relatively long interval ordinarily elapsing between the production and consumption of butter and cheese undoubtedly renders the danger of typhoid infection much less than in the case of milk. The life of the cholera spirillum in butter and cheese is much shorter than that of the typhoid bacillus, and the danger of contracting

* Ebstein: Deut. med. Wochenschr., 1896, 22, pp. 129, 154.

† Thiele: Deut. Militärärztl. Ztschr., 1900, 29, p. 548.

‡ Lafar: "Handbuch der Technischen Mykologie," 2, p. 31.

§ Rabinovitsch: Ztschr. f. Unters. d. Nahrungs u. Genussm., 1900, 3, p. 801.

‖ Harrison: Landw. Jahrb. d. Schweiz, 1900, 14, p. 317.

cholera from the use of these foods is probably so slight as to be negligible. It is conceivable that the various milk products, just like other foods, may be infected independently after manufacture, and precautions to prevent such chance contamination are especially necessary in the case of foods that, like these, are commonly eaten without cooking.

CHAPTER XXXII

BACTERIA AND THE NITROGEN CYCLE

The fact that the chemical element nitrogen enters into the composition of all living things raises a number of important problems. One of these relates to the available sources of nitrogen. Not all forms of nitrogen are capable of being built up directly into living matter. The complex nitrogen substances in the body after death are disintegrated by bacterial activity, and it is well known that ammonia (NH_3) is one of the products of this decomposition. This nitrogenous compound is not an available food for forms of animal life, although it is directly utilizable by some of the higher plants. Certain bacteria, however, can oxidize ammonia to nitrates. It is a familiar fact that all animals depend ultimately upon plants for their supply of nitrogen, and that the higher plants derive their nitrogen for the most part from nitrates in the soil. The conversion of ammonia into nitrate by bacterial agency is, therefore, of peculiar interest, both practically and from a broad biologic point of view. Again, the atmosphere is a great reservoir of nitrogen, but in its elementary gaseous form nitrogen is wholly inert and useless for all the higher forms of life. In recent years it has been found that certain micro-organisms possess the singular ability of fixing free nitrogen. The supply of available nitrogen is, therefore, practically inexhaustible and to a considerable extent under control.

The relation of bacteria to nitrogen compounds may conveniently be considered under three heads: (*a*) Nitrogen-fixation, (*b*) Nitrification, (*c*) Denitrification.

(a) **Nitrogen-fixation.**—It is a striking fact that the store of nitrogen in ordinary uncultivated soil rich in vegetable matter increases naturally without human interference. Exact analyses have shown that the increase is due to the annexation of atmospheric nitrogen; the agency of micro-organisms in this process is attested by the fact that heated soil fails to show any nitrogen assimilation.

Nitrogen-fixation by Soil Bacteria.—Winogradsky was the

first to demonstrate the share of a particular micro-organism in this process. Clostridium pastorianum (Winogradsky, 1895*) is a spore-forming anaërobe very closely resembling the butyric acid bacilli morphologically, but differing from them in its inability to ferment lactose and some other substances. When grown in a nitrogen-free solution of mineral salts and dextrose, the total nitrogen assimilation in twenty days may amount to as much as 53.6 mg. per liter. Winogradsky did not find any other organism capable of fixing free nitrogen, but more recently Beijerinck† (1901) has discovered a group of large aërobic bacteria which also possess this property.

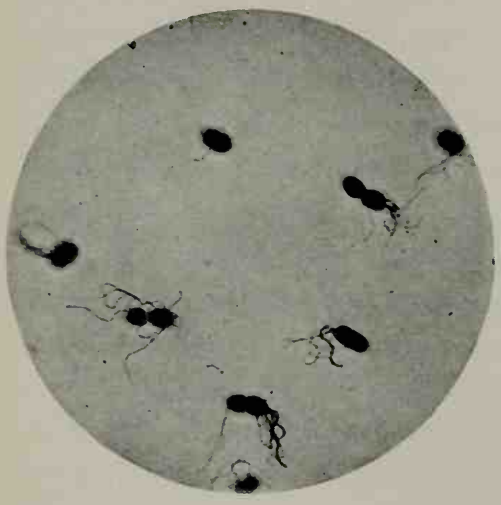

Fig. 145.—Azotobacter agile. ×1000 (Zettnow).

The name *Azotobacter* has been bestowed upon this genus, and several species have been described. One of the two species first described by Beijerinck (A. agile) is decidedly more motile than the other (A. chroöcoccum), and there are other slight differences (Beijerinck). A rather complicated symbiotic relation is believed by Beijerinck to subsist between Azotobacter and Clostridium or Radiobacter, but his view has not been generally accepted. Löhnis and Westermann‡ have studied comparatively a large number of strains from different sources. The cells of Azotobacter are round or oval bodies about 4 to 6 μ in diameter (Fig. 145); they are motile and possess rather short flagella; spore formation has not been observed; coccus forms, filaments, and pear-shaped involution forms are not uncommon; luxuriant growth does not occur on the ordinary culture-media. The amount of nitrogen assimilated is dependent, within certain limits, upon the amount of carbohydrate available, one experiment showing that while a solution containing 1 gm. of glucose gave an increase

* Winogradsky: Arch. d. sci. biol., 1895, 3, p. 297.

† Beijerinck: Centralbl. f. Bakt., 1901, 7, p. 561.

‡ Centralbl. f. Bakt., ii, 1909, 22, p. 234.

of but 7.4 mg. of nitrogen, a similar solution containing 12 gm. of glucose gave an increase of 127.9 mg. (Gerlach and Vogel*). According to Stoklasa† the respiration processes of these organisms are wonderfully active; 1 gm. of bacterial substance (reckoned as dry substance) exhaling in twenty-four hours as much as 1.27 gr. of CO_2. This same author has observed the evolution of hydrogen in pure cultures of Azotobacter. Mannite solutions (*e. g.*, 1000 c.c. tap-water, 20 gr. mannite, 0.5 gr. di-potassium phosphate) and mannite-agar have proved the most satisfactory media for cultivating this micro-organism. Upon solid media the growth often has a black, brown, or yellow tinge.

It has been shown that certain other species of bacteria are able to assimilate free nitrogen. Among them may be mentioned B. mesentericus, B. pyocyaneus, B. prodigiosus, B. asterosporus, and the spore-forming aërobe, B. danicus (Löhnis and Westermann, *loc. cit.*). Certain of the common molds, such as Aspergillus niger and Penicillium glaucum, are claimed by several investigators to be capable of nitrogen assimilation, but the point is still in dispute. As respects algæ and the higher plants, independent nitrogen assimilation, although often affirmed, is not proved, many cases of apparent assimilation by these organisms being due to their symbiosis with some species of Azotobacter. Attempts to increase the yield of cultivated fields by inoculation with certain bacteria alleged to possess the power of nitrogen assimilation (B. ellenbachensis $\alpha =$ B. megatherium?; sold under the trade name of alinit) have not been generally successful, and the results of similar experiments with Azotobacter have also been negative. Azotobacter and Clostridium, as a matter of fact, seem to be universally distributed. It is, hence, more important to modify favorably the factors that influence the activity of these bacteria, such as the physical or chemical condition of the soil, than to add them to soil in which they are already present. These conditions have been sometimes summed up under the name of soil-climate (Bodenklima), and are being made the subject of study by many investigators. It is considered that the

* Gerlach and Vogel: Centralbl. f. Bakt., 1902, ii, 8, p. 669; 9, p. 817; 1903, 10, p. 636.

† Centralbl. f. Bakt., ii, 1908, 21, p. 506.

favorable modifications of the soil-climate for the free nitrogen, living organisms is one of the most important tasks before scientific agriculture. It has been shown already that certain carbohydrates favor greatly the nitrogen enrichment of soil to which they are added. Dextrose, saccharose, and probably also the carbohydrates present in dried grain stalks (straw) are among the substances which increase the nitrogen assimilation of free living bacteria. Phosphates also exert a favorable influence. Potassium sulfate and especially potassium chlorid, on the other hand, are distinctly detrimental to the nitrogen-fixing activity. It is probable also that other bacteria present in the soil affect the fixation of nitrogen either through the action of their products or through direct competition for food material.

Nitrogen-fixation by Nodule Bacteria.—One phase of nitrogen assimilation that has attracted universal attention, and that has long been familiar in certain of its practical aspects, is the accumulation of nitrogen by leguminous plants. One of the commonplaces of agriculture is that while certain crops, notably the grains, exhaust the nitrogen in the soil, others, such as the clovers, peas, beans, and lupines, not only do not diminish the nitrogen-content, but augment it, so that their growth tends to enrich soil impoverished by other plants. Exact experiments have shown that a crop of crimson clover is able to add more than 200 pounds of nitrogen per acre. A long step toward the explanation of this remarkable fact was made by Hellriegel and Wilfarth in 1886.* These observers showed that the tubercles or nodules† (Fig. 146). long known to occur on the roots of the common Leguminosæ, and shown by Frank‡ (1879) to be absent from plants grown in sterilized soil, were not merely reserve storehouses for protein substances, but stood in active causal connection with the assimilation of free nitrogen. The nodules themselves are largely filled with rod-shaped organisms, which were discovered by Woronin§ in 1866, but whose

* Hellriegel and Wilfarth: Centralbl. f. Bakt., 1887, 1, p. 133 (Rev.).

† The root-tubercles were described by Malpighi in 1687 (Opera omnia, Leyden), but first recognized to be normal, not pathologic, structures by Treviranus in 1853 (Bot. Zeit., ii, p. 393).

‡ Frank: Bot. Zeit., 1879, 37, p. 832.

§ Woronin: Bot. Zeit., 1866, 24, p. 329.

bacterial nature was not definitely established until Beijerinck* grew them (1888) on an artificial medium composed of a decoction of pea leaves, gelatin (7 per cent.), asparagin (0.25 per cent.) and saccharose (0.5 per cent.).

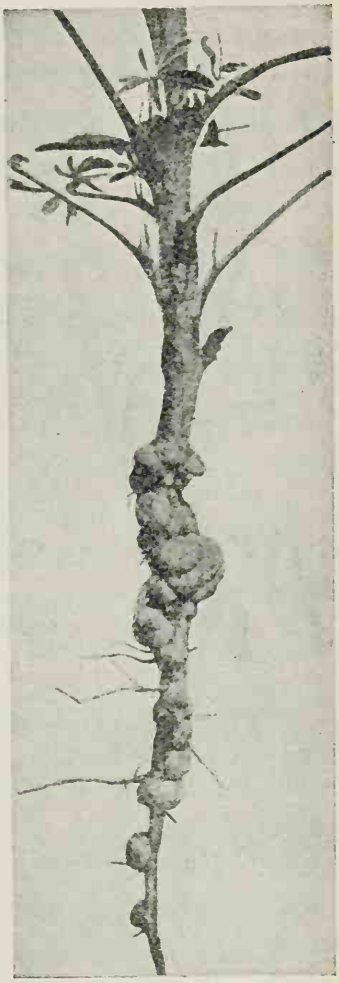

Fig. 146.—Root nodules of Lupinus luteus (Mayer).

The nodule-bacteria (Bacillus or Rhizobium radicicola) when of full size are rather large rods about 1 μ wide and 4 to 5 μ long; they are actively motile, strongly aërobic, and form no spores. On nutrient gelatin small, viscous, non-liquefying colonies are formed; their appearance has been compared to that of fat-droplets. Inside of the nodules the bacteria become metamorphosed into considerably larger branching structures, the so-called bacteroids. Bacteroids may also develop in cultures; they appear with great constancy in media rich in carbohydrates and certain organic acids (Fig. 147). Different species of Leguminosæ harbor bacteroids that are often strikingly different in size and shape. Functional differences also exist; bacteroids that are very active or "virulent" when in association with one species may refuse to form nodules on the roots of a closely allied species. Such facts have been thought by some observers to indicate the existence of a large number of more or less independent varieties of nodule bacteria. Others would restrict classification to two or more groups, but thus far there has not been general agreement upon the features characterizing such groups. Certain investigators have succeeded in transforming apparently independent varieties into one another, thus proving their essential identity. On the whole, it must be regarded as uncertain how far the nodule bacteria associated with different species of Leguminosæ are distinct, but there are probably at least two groups.

* Beijerinck: Bot. Zeit., 1888, 46, p. 725.

The view once held that the relation between nodule bacteria and host-plants is from the start one of true symbiosis in which both organisms uniformly derive benefit from the association has lost ground in the face of recent researches. So far from welcoming the advent of B. radicicola to its tissues, the host-plant offers a determined resistance. The root-hairs constitute the usual portal of entry, and a very definite tissue reaction is produced at the point of invasion. Decided differences in the "virulence" of the bacteria are noticed (Hiltner*). Some bacteria are not able to effect an entrance at all; others enter and provoke a reaction in the tissues which leads to advantageous nodule formation; and still others injure the host-plant. In brief, the bacteria behave toward the plant, at least in the beginning, like true parasites against which the plant strives to protect itself with all possible means of defense. Eventually a state of equilibrium or kind of armed truce is brought about, in which both bacterium and plant benefit by the association.

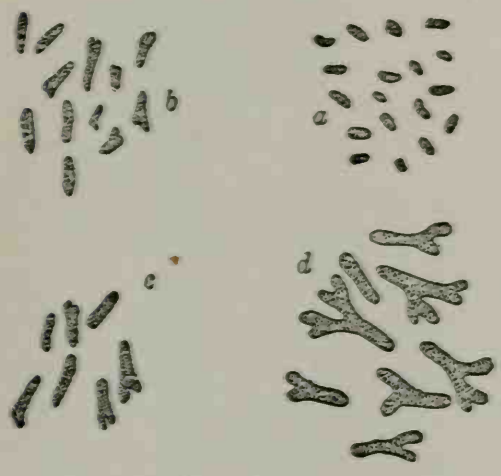

Fig. 147.—Development of root bacteria: *a*, root-bacteroids; *b–d*, forms in nodules of Vicia sativa (Beijerinck).

The size, number, and activity of the nodules depend upon the qualities of the invading bacteria and upon the resisting powers of the host. As an example of the relation between plant and bacterium may be mentioned the action of saltpeter (potassium nitrate) in preventing nodule formation. The addition of a small quantity of this salt to a water culture of a nodule-forming plant suffices to abolish nodule formation altogether. According to Hiltner, the effect of saltpeter is due less to any strengthening of the plant's resistance than to its direct influence upon the nutrition of the bacteria. It may, however, increase the resistance of the plant by lessening its "nitrogen hunger." Inoculation experiments have brought out the interesting fact that the bacteria obtained from active nod-

* Hiltner: Arb. a. d. kais. Gesund., 1906, 1, p. 177.

ules confer upon the plant immunity toward bacteria of the same virulence or of lower virulence; only those bacteria possessing a higher virulence than the ones in the nodules are able to penetrate the roots. There is thus a natural adjustment between the resistance of the plant and the invasive power of the micro-organism.

The question how the possession of root-nodules enables the leguminous plant to transfer free nitrogen from the atmosphere to its tissues has received various answers. Frank, one of the earliest investigators in this field, came to the conclusion that nitrogen assimilation was a property of all green plants, and that the nodule bacteria simply acted as a "stimulus" to provoke its more intense manifestation. The fact, however, that no direct nitrogen-fixation by green plants could be proved weighed heavily against this view, which, indeed, was soon abandoned by its author. Subsequent researches have plainly shown that the accumulation of nitrogen takes place first of all inside the nodule, and that the bacteroids are the seat of the active processes. B. radicicola is able of itself in pure culture to fix atmospheric nitrogen, but in much smaller quantity than in the legumes. Granting that the bacteroids gather nitrogen, how is it transferred to the plant? It has been assumed that the bacteroids are bodily absorbed, but against this supposition stands the disproportionately small quantity of nitrogen in the bacteroids of all the nodules of the plant as compared with the total nitrogen gain of the plant. Nobbe and Hiltner* cite an instance in which a plant had taken 1 gm. of nitrogen from the air, although all the nodules on its roots weighed only 300 mgm. Still another conception, based upon definite chemical observation, has been recently received with much favor. This is that certain compounds formed by the bacteroidal protoplasm are soluble and diffusible through the cell wall, and that these, passing out from the bacteroids, are taken up by the host-plant.

Mazé based an interesting theory of nitrogen utilization upon the great viscosity of cultures of Bacillus radicicola. The viscosity is due to the presence of a gum which is a slightly modified portion of the capsule or outer portion of the cell wall of the organism. It was Mazé's assumption that this gum or mucus was a nitrogenous compound, and that the simultaneous production of this substance and the fixation of nitrogen in solution was proof of its

* Nobbe and Hiltner: Centralbl. f. Bakt., 1900, II., 6, p. 449.

connection with the latter process. Buchanan,* however, has shown that the gum contains no combined nitrogen, but is a carbohydrate substance closely related to the dextroses produced by other groups of bacteria. Its connection with the fixation of nitrogen by the legume organism is, therefore, improbable.

Broadly considered, therefore, the process of nitrogen-fixation by leguminous plants consists, first, in the penetration of the root tissues by certain bacteria which establish themselves there in a sort of half-parasitical, half-symbiotic relation; second, in the accumulation of nitrogenous substances by the bacteria under the influence of the abundant carbohydrate food-supply available in the plant tissues, the nitrogen used in the constructive process being derived from the atmosphere; and, finally, in the appropriation by the plant of the nitrogenous compounds contained within or diffusing out from the nutritionally and structurally modified bacteria (bacteroids). The conditions under which the plant extracts nitrogenous substances from the bacteroids is yet unexplained, but there are facts that seem to connect the phenomenon with a state of "nitrogen hunger," or lack of other sources of nitrogen supply, such as the nitrates of the soil or the nitrogenous stores in seeds. The "virulence" or invasive power of the micro-organism may be connected with a similar condition in the plant.

Many attempts have been made to utilize the enrichment of the soil that results from nitrogen-fixation. The custom of green manuring,—that is, of plowing under leguminous crops,—which has been long practised empirically, has won much wider extension as a consequence of the establishment of its underlying principles. The discovery that certain soils on which leguminous plants grow feebly could be made to yield much more luxuriantly by soil inoculation has given rise to a train of experiments having for their purpose the perfecting of the relations between bacteria and plants. In some of the earliest ventures, soil obtained from fields where the proper bacteria were present in abundance was used for infecting other fields where leguminous plants failed to grow or developed poorly. The results were in some cases brilliantly successful. Following up this success, pure cultures of nodule bacteria were employed experimentally and were marketed on a large scale under names such as "nitragin" or "nitro-culture." Impregnation of

* Buchanan: Centralbl. f. Bakt., II., 1909, 22, p. 371.

the soil with these pure cultures has by no means been uniformly successful, although in some cases it has given unquestionably good results. Inoculation of seeds with pure cultures of the nodule bacteria has led in many hands to somewhat better results than inoculation of soil, but cannot be unreservedly depended upon. One of the reasons for the rather frequent failures reported is the lack of the requisite technical skill and judgment in the application of pure cultures; another is that the presence or absence of proper nodule bacteria is only one of many factors that determine the prosperity of leguminous plants; and still another is that the "virulence" of the culture is at present not wholly susceptible of control. The upshot of practical experience in the United States has been that the use of pure cultures is attended with much uncertainty, and that "the simplest and surest and most economical method of inoculation is by means of well-infected natural soil, collected where the proper bacteria are found in abundance (as shown by the tubercles on the roots of the plants) and scattered over the field to be seeded at the rate of one hundred pounds or more per acre."* It can hardly be doubted, however, that greater precision will eventually be introduced into the practice of soil inoculation, and that the use of pure cultures is likely in the future to become more important than at present.

As already stated, all the members of the family of leguminous plants are endowed with nodules. In this respect they stand almost but not quite alone, since similar nodules have been observed on other plants, notably the alders. The alder nodules apparently sustain the same physiologic relation to the plant as do the leguminous nodules, and enable the alder to gather nitrogen from the atmosphere. There has been much dispute as to the nature of the organisms present in the alder nodule, but several investigators agree in regarding them as very much like the bacteroids, although hyphomycetal characters are rather more pronounced.

A peculiar mycelial growth, known as mycorrhiza, was observed first in association with the roots of orchids, and has since been found in and upon the roots of many other plants; probably the majority of the higher plants are in relation with it either constantly or occasionally. A number of different molds, some of them belonging to common species, are able to develop this singular structure.

* Illinois Agr. Exp. Sta. Cir., No. 86.

While there are many points about the physiologic significance and development of mycorrhiza that are far from being elucidated, it seems to be definitely established that at least the endotrophic mycorrhiza is able to fix free nitrogen. So far as determined, the protoplasmic changes within the hyphæ are like those in the bacteroids, and the whole physiologic process of nitrogen-fixation and plant-absorption is probably the same. Possibly the ectotrophic mycorrhiza has the same function, but this seems doubtful.

(*b*) **Nitrification.**—The complex nitrogen compounds that are among the most important constituents of the body-substance of all forms of life furnish a source of energy not overlooked by bacteria. As soon as an animal or plant dies and the influences that restrain bacterial activity vanish, a breaking-down process, due to bacteria, sets in, which ends in producing substances that are chemically of simple structure. Practically nothing is known about the earliest stages of protein decomposition, not only because the constitution of the protein molecule is largely conjectural, but because the process is almost hopelessly complicated by a variety of modifying influences. Eventually out of the seething caldron of molecular disintegration emerge such relatively simple bodies as the organic acids and amins, mercaptan, sulfureted hydrogen, carbon dioxid, and ammonia. Some of these substances are susceptible of further decomposition. Ammonia, for instance, which is produced abundantly from nitrogen-containing compounds, may be oxidized to nitrites, and the nitrites oxidized in turn to nitrates. This process has received the name of **nitrification.** Apart from its theoretical interest, nitrification is of great agricultural importance, since it is the means by which the ammonia produced from decaying vegetable matter and from manures is converted into a form utilizable by the growing plant.

Like other processes of oxidation, nitrification was long believed to be due simply to the action of atmospheric oxygen, or in some cases to that of ozone. The share of living micro-organisms in the process was first definitely foreshadowed by Pasteur's discoveries concerning acetic fermentation, another oxidation process. Pasteur himself clearly expressed his conviction concerning the essential nature of nitrification in 1862, but his suggestions were not acted upon until Schloesing and Müntz took up the question in 1877.*

* Schloesing and Müntz: Compt. rend. acad. d. sci., 1877, 84, p. 301; 85, p. 1018; 1878, 86, p. 892; 1879, 89, pp. 891, 1074.

These investigators carried on a series of extensive researches which showed convincingly that living organisms were at the bottom of the phenomenon. Chemical substances like chloroform, that check or interfere with microbes, prevent the process of nitrification; heating to temperatures that effect sterilization likewise abolishes it; on the other hand, temperatures that favor the activity of bacteria and their allies promote nitrification. While thus successful in demonstrating that micro-organisms were answerable for the occurrence of the natural process of nitrification, Schloesing and Müntz were not able to fix the responsibility upon any particular species. In fact, for some time it remained doubtful whether many different kinds of bacteria might not possess the ability to oxidize ammonia to nitrates. The isolation of an unmistakable nitrifying organism in pure culture was first accomplished in 1888 by Winogradsky.*

It appeared from Winogradsky's researches that the main reason why previous investigators had been baffled in their efforts to isolate a nitrifying organism was that they placed too implicit confidence upon the ordinary gelatin culture-medium. The nitrifying organism does not grow upon nutrient gelatin, and while readily cultivable upon solutions containing simple ammonium salts, is distinctly inhibited by the presence of organic matter. At first it was supposed that the whole process of nitrification from ammonia to nitrates could be completed by a single species, but it was later found that the chemical division of the process into two stages, first, the oxidation of ammonia to nitrites, and then that of nitrites to nitrates, corresponded to the physiologic activity of two different groups of micro-organisms.

Nitrification may be readily provoked in solutions of certain mineral salts by the addition of a small amount of ordinary cultivated soil. Provided the nitrifying organism is present and organic matter is absent, the process is not interfered with by the presence of foreign micro-organisms. A simple nitrifiable solution used by Winogradsky in his researches has the following composition:

Ammonium sulfate	1 gm.
Potassium phosphate	1 "
Well-water	1000 c.c.
Basic carbonate of magnesia in excess.	

* By the dilution method.

The fact that the transfer of a small quantity of material from a solution that had undergone nitrification sometimes induced complete nitrification in a fresh solution, sometimes carried the process only to the formation of nitrites, and sometimes failed altogether, was at first explained by assuming that the nitrifying organism had become weakened, but the discovery that the production of nitrites and that of nitrates were independent processes, due to the activity of distinct organisms, finally afforded the true explanation. Nitrites cannot be formed unless the nitrite-forming organism is present: if the nitrite-former alone is present, the process stops midway; if the nitrate-former alone, the first step cannot be taken.

The nitrite-forming organism discovered by Winogradsky has received the name *Nitrosomonas*. Unlike the common bacteria, it has a definite life-cycle. When a vigorous culture is inoculated into a suitable mineral solution, a strong nitrite reaction develops by the end of four or five days. At this time scattered cells are few, most of the organisms being gathered in compact zoöglea-like masses in the sediment at the bottom of the flask. Staining with a weak solution of iodin in potassium iodid brings out the structure of these masses most satisfactorily (Winogradsky). Some days later (seven to ten) these aggregates are found to have resolved themselves into separate ellipsoid cells, which bear a flagellum on one end and swim actively about through the fluid. After twenty-four to forty-eight hours the swarming cells become quiescent and sink again to the bottom, where they remain singly or joined in small groups. Variations from this process are not uncommon, but Winogradsky regards the development just described as typical. The zoöglea cells are thought by Winogradsky to represent a resting stage; they are somewhat more resistant to drying than the free cells.

The description given above holds good only for the nitrite-forming organism found in western Europe (Zürich, Gennevilliers). The nitrite-formers found in St. Petersburg (no swarming stage observed), in Java (swarming stage present), and in Quito, South America (no swarming stage certainly observed), differ morphologically from the Nitrosomonas of western Europe and from one another. The peculiarities are constant and are maintained in cultures for a considerable period, but it is yet uncertain whether the differences correspond to true specific differences or are merely the expression

of differences in local conditions. No two forms of the nitrite-producing organisms have ever been found in one locality. The cultivation of Nitrosomonas on solid culture-media was first achieved by Winogradsky by the use of silicic acid jelly ("water glass").* The organism has also been grown in the presence of suitable ammonia salts on washed and purified agar by Beijerinck,† and on gypsum magnesium carbonate plates and on disks of filter-paper by Omelianski.‡ On the silicic acid medium the colonies are quite characteristic, though they always remain small and are best studied with a magnification of about 100 diameters. At first colorless, they soon become dead brown and opaque, the surface colonies being rounded, the deeper colonies more irregular in outline. Later the colonies become granulated and translucent. This change from opaque to translucent colonies corresponds to a morphologic transformation from zoögleæ to free cells.

A highly remarkable physiologic peculiarity of the nitrite-forming organism is its ability to grow normally and produce active oxidation in a medium devoid of all trace of organic substance. The formation of nitrite has been shown by Winogradsky to depend upon the presence of carbon dioxid either free or in loose combination, and is accompanied by the accumulation of organically bound carbon, the amount of carbon assimilated bearing a definite proportion to the nitrogen oxidized. There seems no escape from the conclusion that Nitrosomonas, a colorless organism, and one therefore unable to utilize the energy of light rays, assimilates carbon dioxid by virtue of the energy obtained by the oxidation of ammonia. It is probable that carbon dioxid is the only available source of carbon, since organic substances, like glucose and peptone, not only do not favor growth, but exercise an inhibitory influence upon the nitrite-forming organism, and may even check it altogether. Corresponding to this inability to utilize the carbon of organic compounds is its inability to effect the oxidation of organic nitrogen.

* The successful preparation of this medium requires a considerable degree of experience. Details are given in a paper by Omelianski (Centralbl. f. Bakt., Abt. II., 1899, 5, p. 537). See also Lafar's "Handb. d. techn. Mykologie," 3, pp. 155–8; and Stevens and Temple: Centralbl. f. Bakt., II., 1908, 21, p. 84.

† Beijerinck: Centralbl. f. Bakt., 1896, 2, p. 698.

‡ Omelianski: Centralbl. f. Bakt., 1899, 5, p. 652; 1902, 8, p. 785.

In the presence of nitrogenous substances like urea, asparagin, and egg-albumin, Nitrosomonas remains impotent, and no trace of either nitrite or ammonia formation is found after the lapse of months. Not even the amins, which are so closely related chemically to ammonia, can be attacked.

As already stated, the oxidation of nitrites to nitrates is effected by another organism, which differs in some important respects from the nitrite-former. It is much smaller, is provided with a capsule, and stains with difficulty, the pointed ends not staining as deeply as the middle (Fig. 148). No "swarming stage" has yet been observed. Growth occurs both in a nitrite solution* and on nitrite agar. It is, however, extraordinarily slow; after two weeks the round or oval colonies in the depth of the agar have attained a diameter of only about 30 μ to 50 μ. The colonies that come to the surface are round, colorless droplets, and may reach a size three or four times as great as those in the depths. In the fluid medium neither turbidity nor sediment makes its appearance, and usually no sign of growth can be observed. By repeated enrichment of a culture with nitrite, however, an opalescent veil forms slowly over the walls and bottom of the flask, and microscopic examination shows this film to be composed of spindle-shaped rods that stain with difficulty.

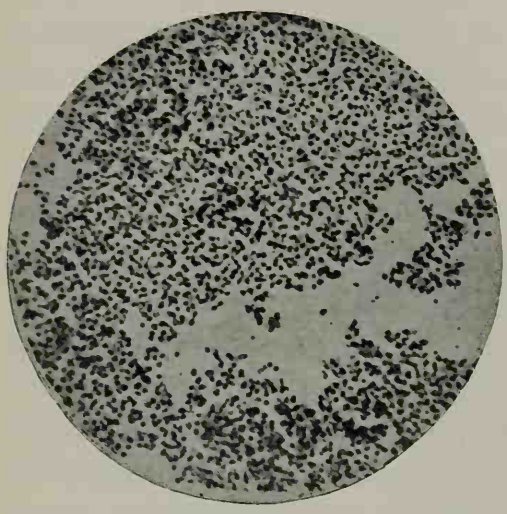

Fig. 148.—Nitrate-former from St. Petersburg nitrate. Agar. Fuchsin. × 1000 (Lafar).

The physiology of the nitrate-former has been less completely worked out than that of the nitrite-producing organism. It seems

* Sodium nitrite (natr. nitros-puriss, Merck)...1.0 gr.
Potass. phosphate.....0.5 "
Magnes. sulfate.....0.3 "
Soda (water-free).....1.0 "
Sodium chlorid.....0.5 "
Ferrous sulfate.....0.4 "
Distilled water.....1 liter

probable, in view of experiments already made by Winogradsky and Omelianski and Gärtner, that, like Nitrosomonas, the nitrate former can obtain its carbon supply only from carbon dioxid. The nitrate-former is less sensitive toward the presence of organic substances than the nitrite-former, although both its development and, to a less degree, the production of nitrates are interfered with to some extent. On the other hand, ammonia exercises a remarkably harmful influence upon the nitrate-former, restraining its development more powerfully than the strongest antiseptic (Winogradsky). Nitrates, even in considerable quantities, do not hinder nitrate formation.

The fact that under varied natural conditions the process of complete nitrification goes on steadily and quite rapidly is not in reality out of accord with the singular physiologic qualities and limitations of the nitrifying organisms. Although neither nitrite- nor nitrate-forming organisms are able to generate ammonia from organic substances, they are constantly in association with myriads of bacteria in the soil and in water which do produce ammonia in abundance. Given ammonia as a starting-point, nitrite formation can occur, provided too much organic matter be not present, while after nitrite makes its appearance, the nitrate-former can pursue its activity. Ammonia seems to be injurious, especially to the development of the nitrate-former, less so to its oxidizing activity; however, both phases of the nitrifying process can go on simultaneously, provided living cells of the nitrate-forming organism are abundant at the time nitrite is produced. There is hence no real contradiction between the phenomena of nitrification observed under natural conditions and the characteristics of the nitrifying organisms exhibited in pure culture.

(*c*) **Denitrification.**—Essentially different chemical and bacterial processes are quite commonly included under this head. Among these are a variety of reducing processes, such as the reduction of nitrates to nitrites and ammonia, the reduction of nitrates and nitrites to gaseous oxids of nitrogen (N_2O, NO), and the complete reduction of nitrates and nitrites with evolution of nitrogen gas ("true denitrification"). Other processes, such as the setting free of nitrogen in the course of protein decomposition and the constructive utilization of nitrate nitrogen, are quite far removed from the strictly reducing actions.

The ability to reduce nitrates to nitrites and ammonia is a widespread bacterial characteristic; Maassen,* who investigated the reducing power of one hundred and nine kinds of bacteria, found eighty-five to possess this power. In reducing processes of this nature the presence of organic nitrogenous matter is necessary; on the other hand, glucose and other carbohydrates exert a hindering influence. It is not clear whether any physiologic significance should be attributed to the reduction of nitrates to nitrites, or whether the process is incidental and the reduction due simply to the chemical products of the bacteria. It is possible that, as in the case of the true denitrifying bacteria, to be considered presently, the reduction is caused by the need of the cells for oxygen.

The formation of the oxids of nitrogen (N_2O and NO) is less commonly observed. It is not yet known to what extent this phenomenon is dependent upon conditions of growth, or how far it is a specific peculiarity of certain species. Among the more familiar species that can give rise to these gases under suitable conditions is B. pyocyaneus.

The "true" denitrifying bacteria, those that are able to reduce nitrates with the formation of free nitrogen as an end-product, are relatively few in number, but include such well-known species as B. coli, B. typhosus, B. fluorescens, and B. pyocyaneus. In nitrate broth (*cf.* p. 34) denitrifying species cause a foamy appearance which is quite characteristic, and is due to the liberated nitrogen. Light is thrown upon the physiology of the denitrifying bacteria by the circumstance that while they ordinarily grow under aërobic conditions, they can also thrive anaërobically, provided nitrite or nitrate be present. The inference seems plain that in these cases the reduction of nitrates is to be regarded as due to the respiratory needs of the micro-organism, which wrests the oxygen from its combination with nitrogen, setting free the latter as a gas. Jensen,† however, points out that denitrification must always be accompanied by oxidation processes. The same author has found that denitrifying bacteria produce considerably more peroxidase than other bacteria. The necessary conditions for denitrification are: (1) the presence of nitrates; (2) the presence of

* Maassen: Arb. a. d. kais. Gesund., 1901, 18, p. 21.

† Centralbl. f. Bakt., II., 1909, 22, p. 314.

certain specific micro-organisms; (3) a considerable amount of readily assimilable organic substance; (4) limited access of oxygen.

The practical importance of soil denitrification for agriculture has been considerably exaggerated. Loss of nitrogen by this means can play an important part only if very large quantities of fresh manure are added to a soil exceedingly rich in nitrates or if manure and nitrates be added simultaneously.

CHAPTER XXXIII

BACTERIA IN THE ARTS AND INDUSTRIES

From its birth bacteriology has been more or less concerned with practical pursuits. As has been pointed out in another place (p. 20), the science owes its origin largely to the studies of Pasteur upon the phenomenon of fermentation; in particular, to his memorable researches upon the diseases of beer and wine. The further development of bacteriology has brought it unexpectedly into contact with a variety of industries and occupations outside of the alcoholic fermentation, and has unveiled previously unseen opportunities for exploitation and utilization. The share of bacteria in advantageous or commercially valuable processes has so far been less thoroughly exploited than their agency in inciting disease, but the field already opened is a wide one. Much of the work that has been accomplished in this direction is special and technical; space forbids its consideration here except in its broader aspects. Some of the applications of bacteriology to agriculture have been touched on already in connection with the nitrogen cycle and with the rôle of bacteria in the dairy, but there are also several special industries which are in part or altogether bacterial processes, or which depend upon the proper application of bacterial methods.

Bacteria in Tanning.—The object of tanning, which is to treat the animal skin so that it shall offer the greatest possible resistance to decomposition, at the same time that it retains its adaptability to the variety of purposes to which leather is put, is influenced by bacterial activity at several points. In the process of tanning, hides which have been previously protected against decomposition by drying or salting are freed from hair either by a carefully controlled decomposition, in which Proteus (p. 382) is said to be specially concerned, or by simple chemical treatment with sulfite of sodium or lime. After depilation, the hides are "drenched" or steeped in a liquor prepared according to various formulas that read like the therapeutic mixtures of the middle ages. Animal excrements, especially

the droppings of hens, pigeons, and dogs, are a common ingredient; bran is also used commonly in these mixtures. In the "bran drench" the essential feature seems to be that the starch of the bran is hydrolyzed and converted into sugar, and an acid fermentation occurs in which lactic acid is usually most abundant, although acetic, formic, and butyric acids are also found. The lactic acid is the active agent in removing the lime from the skin. Gas-forming bacteria are present in this fermentation, one of them having been described under the name of B. furfuri.* It is obvious that the heterogeneous character of the mixture introduces many uncertainties into the process. Attempts have been made to put the treatment on a more systematic basis. A distinction has been made between "bating" and "puring," bird dung being used in the first process and dog dung in the puring of the lightest leather. In spite of the great disadvantages that attend the use of such substances, practical tanners assert that they give results with some skins, notably goat skins, that no other material does. Substitutes for the objectionable animal feces have been proposed and used with some success. Wood† has carried on extended researches on the kinds of bacteria concerned in "bating" and "puring." One organism, B. erodiens, has been used in pure culture with results said to be very satisfactory. (See Wood, *loc. cit.*) The bated hides are next placed either in a tan-pit (the coarse kinds destined for sole-leather) or in bark liquor (the thinner skins). The souring of the bark liquor is considered in Europe to influence favorably the quality of the product, making the leather soft and supple. Tanners have sometimes seeded fresh bark liquor with old soured liquor in order to insure that the fermentation take a proper course. It is uncertain whether the favorable effect is due primarily or wholly to the acid or whether other bacterial products are concerned. As might be expected, numerous micro-organisms of different sorts, bacteria, yeasts, and molds, occur in the bark liquor. Varying amounts of carbohydrates and nitrogenous compounds in bark liquors of different origin influence materially the souring process and determine to some extent the character of the product. Amer-

* Perhaps the same as B. gasoformans.

† Wood: Jour. Soc. Chem. Ind., 1894, p. 218; 1895, p. 449; 1898, pp. 856, 1010; 1899, pp. 117, 990.

ican tanners for the most part avoid sour liquor. Although the souring of the bark liquor is a bacterial process, little advance has been made toward the elucidation of the share of particular species.

The Curing of Tobacco.—The organic substances present in the leaves of the tobacco plant are exposed, at the death of the plant, to a variety of bacterial influences. The first stage in the treatment of the leaf, the drying in specially prepared rooms, is not, however, a bacterial process, the conspicuous changes that occur, such as the dissolving of the starch and the browning, being due to leaf enzymes. Certain maladies may overtake the leaf at this stage: some of these are caused by saprophytic fungi (*e. g.*, Botrytis); the so-called "pole-burn" has been attributed in part to putrefactive bacteria.

In the next stage the dried tobacco leaves are ripened by being heaped up in great piles which undergo heating and fermentation. The temperature in the interior of these masses may rise as high as 50° C., exceptionally as high as 61° (Suchsland). Among the more noteworthy chemical features of this fermentation is the loss of nicotin, which amounts to about 28 per cent.

The share taken by micro-organisms in the ripening process has been and still is a matter of dispute; some observers hold that the oxidizing enzymes of the tobacco leaf itself are responsible for the changes that occur in this stage. Since a desirable aroma and other qualities of a successful product are dependent upon the course of the fermentation process, it is a matter of no small importance to the tobacco industry that the nature of the process should be clearly understood as the first step toward efficient control. Bacteria of a great variety of kinds are naturally not lacking in the fermenting masses of tobacco leaves. Many attempts have been made to determine what kinds, if any, are of significance in the ripening process.

The majority of those investigators who have studied in the laboratory the ripening of tobacco after inoculation with pure cultures of bacteria have obtained a product that, on the whole, possesses a more satisfactory aroma than tobacco ripened under natural conditions. The bacteria found in tobacco-curing seem to belong for the most part to the Proteus, Subtilis, and Mycoides groups.

Some investigators (Suchsland, A. Koch) have used for inocula-

tion cultures of bacteria obtained by them from tobacco "of the finest quality." It is said that spraying tobacco leaves with these cultures has imparted highly satisfactory qualities to a grade of tobacco which, if allowed to ferment simply by the aid of native bacteria, would have been of inferior character. The nature of the culture employed in this case has not been divulged, and it seems to be a fact that the method of using such cultures has not won any wide acceptance in the tobacco industry.

The relatively high temperatures in the interior of the ripening masses undoubtedly favor the development of thermophilic varieties; Vernhout has reported the constant occurrence of a thermophilic bacterium, belonging to the potato-bacillus group, in fermenting leaves of Java tobacco.* Additional evidence in favor of some bacterial share in tobacco-curing is given by the existence of the practice of "petuning." This custom consists in sprinkling the unripened leaves with a liquid prepared in various ways, such as by infusing old tobacco, mixing water with molasses, rum, etc. The petuning liquid used on different plantations is different and is often prepared by exact formulas. Havana tobacco fermented in the United States does not develop the true "Havana flavor." There seems to be no doubt that petuning enhances the aroma and value of the product, and that in some manner the quality of the tobacco produced on different plantations is affected by the nature of the petuning liquid applied. Such a fluid may conceivably act either by stimulating the growth of desirable bacteria already present on the leaves, or by infecting the leaves with the varieties that impart aromatic qualities.

On the other hand, Loew† has expressed the opinion that the curing of tobacco is not in essence a bacterial process, but is due to the action of leaf enzymes (oxidase, peroxidase, katalase) which effect all the chief changes that are observed. According to Loew's view, bacterial intervention is not necessary to secure a desirable product.

Both enzymes and bacteria are perhaps concerned in the curing process, although the relative and absolute importance of the two factors is still uncertain. If bacteria grow at all upon the

* See Lafar: "Hand. d. techn. Mykologie," 5, p. 10.

† Loew: Report No. 59, U. S. Dept. of Agri., 1899.

fermenting tobacco leaves, there seems no escape from the conclusion that their products must permeate to some extent the ripened tobacco. Whether the bacterial influence preponderates over that of the enzymes, and whether certain species give a better flavor than others, cannot at present be positively asserted. Jensen* has reported experiments which cast doubt on the microbic nature of the tobacco fermentation. The process is not hindered by germicides such as mercuric chlorid, formalin, and chloroform; on the other hand, the characteristic qualities of the fermentation can be produced, at least in part, by heating the tobacco leaves at a temperature of 90° to 100° C. for ten minutes to two hours. The characteristic rye-bread odor of freshly fermented tobacco, for example, can be brought about by this procedure. It is true that the oxidizing enzymes described by Loew are destroyed by high temperatures like those used in Jensen's experiments, so that according to these results both leaf enzymes and bacteria would seem to be excluded as essential factors in tobacco curing.

The Preservation of Foods.—The fact that many valuable foods, both of animal and plant origin, are abundant at certain seasons of the year and in certain localities, and are lacking or scarce in others, has made it a matter of great importance to the human race to find some way of preserving such food-products against natural decomposition. Simple methods of food preservation have long been practised. One of these is drying. Fish, meat, and fruits may be exposed under suitable conditions to sun and air, and the consequent loss of moisture renders the organic substance unadapted for bacterial growth (p. 71). Meats are sometimes smoke-dried, a process into which, besides drying, another factor enters, namely, the impregnation of the meat with antiseptic substances, such as creosote, present in ordinary wood smoke. Neither smoking nor pickling, however, can be depended upon to free meat from any pathogenic bacteria it may originally contain. Tubercle bacilli in smoked meat and the bacilli of swine erysipelas in pickled pork, for example, have been observed to retain their vitality and virulence for long periods.

The addition of chemical substances that check or inhibit decomposition is a time-honored mode of food preservation. Common

* Jensen: Centralbl. f. Bakt., II., 1908, 21, p. 469.

salt and sugar are frequently used for this purpose. Preserves to which a large quantity of sugar has been added and meats pickled in brine are not adapted for bacterial growth because of their great avidity for water. A germ falling into a strong sugar or salt solution is unable to grow because the density of the solution is greater than that of the cell protoplasm of the germ and tends to extract water from it. "Condensed milk" owes its keeping qualities when exposed to the air to the large amount of sugar it contains. The acetic acid of the vinegar used in pickling is another well-known chemical preservative. Sometimes rather strongly germicidal chemical substances, such as salicylic acid, borax, boracic acid, formaldehyd, and sodium sulfite are employed as food preservatives. While these last-named compounds undoubtedly prevent the decomposition of food, there is evidence that they are likewise injurious to the health of the consumer.

In some few cases the access of bacteria to the decomposable substance may be partially interfered with so that decay or putrefaction is to some extent retarded. The shell of the hen's egg is so porous that bacteria can pass through after the egg is laid, and many attempts have been made to preserve eggs by giving them an impervious coat. The most successful of the substances experimented with is the commercial fluid known as "water-glass," a syrupy mixture of sodium and potassium silicate (1 part of water-glass to 10 of water), but success in preservation is only partial, since eggs have usually become contaminated with bacteria while still in the oviduct, and hence at the time they are laid contain a considerable number of germs. Eventually eggs treated with water-glass will decay.

Many fruits, such as apples and pears, can be kept for a long time from spoiling if the skins are carefully wiped and dried and if bruising is avoided. In other words, any measure that tends to make difficult the growth or ingress of bacteria is an aid toward preservation.

A familiar method of food preservation and one widely employed at the present day is storage at low temperatures. Bacterial multiplication is greatly checked by temperatures a few degrees above freezing, and ceases at or near the freezing-point. Refrigeration is consequently an effectual hindrance to decomposition.

Much food in the large cold-storage warehouses is maintained in a frozen condition, and its wholesomeness is in no degree impaired

throughout a considerable period, although it is evident that the practice calls for constant watchfulness.

The most extensively used and by far the most important method of food preservation consists in the use of heat. This method was devised by Appert in 1810. The principles underlying the well-known process of canning, which are, in fact, those of ordinary laboratory sterilization, are first the destruction of all germs originally present, and second the prevention of subsequent contamination. In practice the process may fail either through incomplete sterilization or through failure to seal hermetically. One of the chief difficulties in practical canning is caused by the presence on vegetables of the spores of anaërobic soil bacteria which are not killed by simple boiling. The sterilizing or "processing" of peas, and especially corn, gives much trouble. If all spores are not killed, gas may be produced and the cans "swell," or the contents may become sour without any external signs of spoiling. In canning corn it has been found necessary to employ a temperature of 250° F. (121° C.) for sixty-five minutes under conditions that insure penetration, in order to preclude spoiling. To this end the cans are placed in a steam retort, in a bath of oil or in water to which certain chemicals, such as calcium salts, are added to raise the boiling-point. In this way the necessary high temperatures are reached. Leaks in the can, as well as insufficient sterilization, may also allow opportunity for bacterial growth. Too thin tin plate, poor soldering material, or imperfect soldering may be responsible for the admission of germs to the sterilized contents. If sterilization is complete at the outset and bacteria do not subsequently find access, canned goods will keep indefinitely without deterioration.

Vinegar-making.—The oxidation of alcohol to acetic acid in weak alcoholic solutions, such as cider and wine, was for a long time thought to be a purely chemical process. It is a fact that when finely divided platinum, the so-called platinum black, is mixed with dilute alcohol, oxidation of the latter occurs, accompanied by the evolution of heat, and at first the "mother of vinegar" was thought to act in a similar manner. The oxidation by platinum black, however, unlike the natural fermentation, takes place much more rapidly at high temperatures, and goes on unimpeded in the presence of an amount of acid that completely prevents the ordinary fer-

mentation process. Pasteur's investigations finally made clear the share of living micro-organisms in this as in other natural fermentations. The equation

$$\underset{\text{Alcohol}}{C_2H_6O} + \underset{\text{Oxygen}}{O_2} = \underset{\text{Acetic Acid}}{C_2H_4O_2} + \underset{\text{Water}}{H_2O}$$

is only approximately correct, the actual chemical changes in which the micro-organisms participate being much more complicated.

The acetic acid fermentation of cider proceeds most satisfactorily at temperatures of about 18° to 24° C., and is greatly facilitated if vinegar containing "mother of vinegar" is first added to the cider. The "mother," or "Mycoderma aceti," consists of a felt-like scum which commonly forms on the surface of cider or wine during its conversion into vinegar. Different micro-organisms are found in this pellicle, and there is no doubt that several distinct species or varieties are able to bring about the acetic acid fermentation. The acetic acid bacteria usually met with, however, possess certain characteristics in common, such as a marked tendency toward pleomorphism and the production of involution forms. Long filaments which break up into bead-like chains are usually observed, and portions of the filaments are often greatly swollen. The essential physiologic requirement of the acetic acid fermentation is an abundant supply of oxygen, for without this the oxidation of the alcohol cannot be effected. When ordinary casks are used for vinegar-making, they should be not more than two-thirds to three-fourths filled with apple-juice, and the outer air allowed free access to the cask through an open bung-hole or one stopped with a cotton plug. Special "generators" are in use for hastening the formation of acetic acid by facilitating the absorption of oxygen. A common method in Germany consists in allowing the alcoholic fluid to trickle slowly through a cask filled with shavings impregnated with old vinegar, thus exposing the fluid to the air in thin layers. In the ordinary farm management of vinegar-making freshly pressed apple-juice placed in casks and allowed to stand in the cellar (at a temperature of about 7° to 13° C.) completes the alcoholic fermentation in about five to six months. If the cider is then removed and kept at a warmer temperature, the acetic acid fermentation may be car-

ried out in fifteen to eighteen months, or if left at the lower temperature, in twenty-one to twenty-four months.*

It is sometimes noticed that vinegar allowed to stand for a long time loses its sourness, and that finally all the acetic acid disappears. This is due to the action of certain bacteria (B. xylinum, Browne) which, in the presence of oxygen, split up the acetic acid into other compounds. The deteriorative change can be readily avoided by preventing the free access of oxygen after a sufficient degree of acidity has been reached.

Pure cultures of acetic acid bacteria are not in use in vinegar-making. If undiluted apple-juice with a sufficient sugar content is employed, and if the fermentation processes as above outlined are properly carried out, there seems to be little or no difficulty in obtaining a satisfactory grade of cider vinegar conforming to the legal standard of acetic acid content (4 to 4.5 per cent. acetic acid). In other words, the increased trouble and care incident to working with pure cultures does not at present meet with adequate recompense in an increased value of the commodity.

The Fermentation of Sauerkraut.—Several investigators have reported the presence of organisms in sauerkraut which apparently bore a causal relation to the fermentative process. One of these which seems to be especially significant belongs to the Bacillus coli group. Lactic acid and perhaps other organic acids are produced in abundance by this organism. Gruber† has carried out inoculation experiments with pure cultures of the coli-like bacillus isolated by him. The inoculated samples of cabbage are said to have given 'a more delicate and aromatic" product than the control samples, and to have reached the desirable stage in a short time. The sauerkraut fermentation and similar souring processes can only be carried on successfully when the air is at least partially excluded from the fermenting mass, since lactic acid formation is inhibited by the presence of oxygen.

The Bakery Fermentations.—In the making of bread, the action of micro-organisms is manifested in several ways, such as (1) The spontaneous fermentation of dough; (2) the use of leaven;

* Bull. No. 258, N. Y. Agr. Expt. Sta,, 1904.

† Gruber: Centralbl. f. Bakt., II., 1909, 22, p. 555.

(3) the use of yeast; (4) the abnormal fermentations that sometimes cause batches of loaves to spoil.

(1) The natural or spontaneous "rising" which occurs under some conditions in dough made simply with flour and water has been the object of considerable bacteriological study. At first a specific bacillus, designated as Bacillus levans, was thought responsible for the phenomenon. Later Bacillus levans came to be regarded as merely a variety of the Bacillus coli group, representatives of which are known to be found in some abundance on the surface of grains and in meal. Still further observations again appeared to throw doubt on the nature of the bacteria concerned, for some investigators differentiate Bacillus levans from Bacillus coli on the ground of its slow liquefaction of gelatin, its gas ratio, and other qualities.* There seems no reason to suppose that different kinds of aërogenic organisms may not be able under certain conditions to produce the spontaneous rising. More important than the kind of bacteria seems to be (*a*) the carrying out of the process at a low temperature and (*b*) the sugar content of the meal.

(2) The preservation of a small portion of the dough from a previous rising and the thorough kneading of this into fresh dough is a practice of great antiquity. The sour dough, a little of which leaveneth the whole lump, contains, as might be expected, a great variety of micro-organisms. Just as in the case of the micro-organisms in meal, there is some uncertainty in respect to the share of the various organisms in the rising. Yeasts are probably in the main responsible, but at least four different kinds have been found in sour dough, and it has not yet been determined that any one of them is more active than another. Aërogenic bacteria seem to have little or no share in the gas production brought about by inoculation with sour dough. The presence of bacilli of the lactic acid group, however, appears to favor the typical fermentation, since the acid-products not only check the growth of foreign bacteria, but aid in maintaining a suitable reaction for the growth of the yeasts.

(3) The use of brewery yeast, dried or pressed in cakes, is more convenient than the use of sour dough, and, as is well known,

* Some of the descriptions of B. levans suggest B. cloacæ (p. 383).

is now the general practice. Both yeasts and bacteria occur abundantly in the yeast-cakes, but the former are the active agents in the production of gas, which is practically pure CO_2, not as with the aërogenic bacteria mixtures of CO_2 and H. Theoretically the yeast-cells should be so evenly distributed throughout the fermenting mass that the gas from the alcoholic fermentation is regularly and uniformly generated. This is more easily accomplished with the use of brewery yeast than with sour dough.

Pure cultures of yeasts have been successfully employed by several experimenters in the preparation of bread. Certain species have been found particularly well adapted for this purpose, for example, the so-called Race XII, discovered in the Berlin Institute for Fermentation Industries. It is said that bread prepared with certain of these pure cultures contains so little butyric and acetic acids that its digestibility is much greater than that of ordinary bread.

(4) The most frequent and most feared abnormal fermentation in the bakery is that which gives rise to the so-called sticky or slimy bread. This is caused by the common "potato bacillus" —Bacillus mesentericus—an organism which forms highly resistant spores and is hence able to survive the temperature reached in the baking process (often not over 100° C.). The spores of this bacillus are sometimes present in large numbers in flour, sometimes also perhaps in the yeast-cakes. The successful combating of the mischief due to the presence of this very resistant organism has been found extremely difficult. An artificial increase of the acidity of the dough is recommended by some experimenters.

The molding of bread is a very common occurrence, and in general the eating of slightly moldy bread does not seem to be accompanied by any serious injury to health. At the same time, the recorded instances of occasional illnesses attributed to this cause are sufficiently numerous to warrant caution in the use of bread in which molds of any kinds are growing. Penicillium, Rhizopus, and Aspergillus are the fungi that most commonly attack bread, and there is some evidence indicating that poisonous races of these organisms may exist in some localities. Certain Italian observers claim to have extracted toxic substances from both the spores and the hyphæ of some of these fungi. The dis-

ease known as *pellagra,* which is prevalent in parts of Southern Europe and also occurs in the United States, is commonly attributed to the eating of moldy Indian corn. Pathogenic or toxin-producing races of molds are said to occur in samples of maize suspected of having given rise to pellagra, but no general agreement has been reached among investigators of this malady. The opinion most widely held is that there is some relation between pellagra and the eating of moldy corn, but there are some who doubt even this connection.

The Retting of Flax and Hemp.—The fibers of certain plants which are used for textile purposes can only in rare cases be separated mechanically from the rest of the plant tissues. Ordinarily such separation is effected by a fermentation process—the so-called retting or rotting. Sometimes the plants are put directly into standing or slowly running water, sometimes they are left on the ground in such a way that the dew and rain supply the necessary moisture. The process may be accelerated by the use of water warmed to 30° to 32° C. The fermentation consists essentially in the dissolving of the substance which binds the fibers together. This cementing substance is largely composed of certain carbohydrates known as pectin bodies, and it is the solution of the pectin which permits the isolation of the bast fibers.

Not all kinds of bacteria are able to accomplish the pectose fermentation. The water-retting of hemp is attributed to the special activity of an anaërobic bacillus of the butyric acid group ("Clostridium"). The water-retting of flax is also ascribed to a specific anaërobic bacillus ("Granulobacter pectinovorum"). These bacteria hydrolyze the cementing substance by means of an enzyme (pectosinase) which they secrete, and then ferment the simpler products (sugars) which result from the splitting. Some observers have declared that certain common aërobic organisms, such as Bacillus subtilis and B. mesentericus, can bring about the pectose fermentation, but the evidence does not seem to warrant this opinion. Under natural conditions, however, the products of the aërobic organisms aid in bringing about conditions under which the pectose-fermenting anaërobes can thrive, and in this respect may be said to assist in the retting process.

Pure cultures of pectose-fermenting bacteria have been em-

ployed by several observers in the retting process, it is said, with considerable success. Whether natural or artificial methods be employed, the process should not last too long, otherwise the bast fibers themselves will be injured or destroyed. Such injury may probably be brought about both by the pectose fermenters themselves and by cellulose-fermenting bacteria (Omelianski) which may be present.

The Bacterial Destruction of Cellulose.—Under the name cellulose, as is well known, are grouped a variety of nitrogen-free substances which occur especially in the cell-wall of plants and have the general carbohydrate composition indicated by the formula $C_xH_{2y}O_y$. Such substances as cotton, flax, and the Swedish filter-paper used in chemical laboratories are practically pure cellulose. Powerful chemical reagents are not able to effect either the oxidation or the hydrolysis of these bodies, which are completely insoluble. Their disintegration by bacterial agency is, therefore, of special interest. Our knowledge of the cellulose fermentation is due largely to the work of Omelianski.*

Two kinds of anaërobic cellulose fermentation have been especially studied: the hydrogen fermentation and the methan fermentation. For the former Omelianski gives the following balance-sheet of an actual experiment:

Cellulose.		Fermentative Products.	
Amount at beginning of experiment	3.4743 gr.	Fatty acids	2.2402 gr.
Amount left at end of experiment	0.1272 gr.	Carbon dioxid	0.9722 gr.
Decomposed during fermentation	3.3471 gr.	Hydrogen	0.0108 gr.
			3.2232 gr.

The hydrogen fermentation of cellulose is brought about by a long, very slender bacillus, with round terminal spores. No growth occurs usually in the ordinary culture-media, though Omelianski has observed on some occasions very minute translucent colonies on potato.

The methan (marsh-gas) fermentation of cellulose yields, like the hydrogen fermentation, a large amount of fatty acids and an even higher proportion of gas (a mixture of carbon dioxid

* Centralbl. f. Bakt., II., 1902, 8, p. 195; 1904, 11, p. 369; 1904, 12, p. 33.

and marsh-gas). About 50 per cent. by weight of the dissolved cellulose is liberated in gaseous form. Morphologically the bacillus of the methan fermentation is very similar to the bacillus of the hydrogen fermentation, and only slight differences can be noted. Pure cultures have not been obtained. A separation of the two varieties of fermentation, however, is obtained regularly by Omelianski by the method of repeated heatings (75° C. for fifteen minutes), which is based on differences in the life-history of the two organisms. The methan-fermentation organism develops more rapidly than the other variety and gains the upper hand in the early stages of the process. If heat is applied at this stage, the more slowly germinating spores of the hydrogen-fermenting organism are in a resistant stage and survive. On the other hand, successive inoculations of material from the methan fermentation at its height eliminate finally the hydrogen organism, and, when this stage has been reached, heating of a culture no longer yields the results obtained when mixed cultures are so treated. It should be noted that neither of these bacilli stains blue with iodin in any stage of development and that they consequently lack the distinguishing feature of the "Amylobacter" of earlier writers.

In addition to the two common and widely distributed organisms studied by Omelianski, other bacteria, including some aërobic forms, are able to decompose cellulose, but the conditions of their activity have not been adequately determined. A number of cellulose-dissolving molds are also known.

The destruction of cellulose in the alimentary tracts of some of the higher animals, particularly the herbivora with their enormous length of intestine, is undoubtedly chiefly due to cellulose-dissolving bacteria and not to the digestive fluids. The proportion of cellulose broken up in this way in the alimentary tract may reach as high as 75 per cent. of the amount fed, and since some of the products of this fermentation are utilizable by the animal organism, the nutritional significance of the process is considerable.

CHAPTER XXXIV

THE BACTERIA OF AIR, SOIL, AND WATER

Bacteria in Air.—As might be supposed, the number of bacteria in the air bears a close relation to the quantity of larger suspended particles or "dust." There are fewer bacteria in the air of the country than of the city; there are fewer in mountain air than in the air of the lowlands; the air in mid-ocean is nearly germ-free. Pasteur, in an experiment made during the course of his celebrated researches on spontaneous generation, observed that only twelve out of twenty flasks of organic infusion which were opened at a low altitude escaped infection, while out of twenty opened on the Mer de Glace nineteen escaped. Tyndall's experiment at the Bel Alp in Switzerland was a "yet more emphatic instance of the same kind, 90 per cent. of the flasks opened in the hayloft being smitten, while not one of those opened on the free mountain ledge was attacked." These facts, which indicate the relation of the floating matter of the air to bacterial infection, have been supplemented by data obtained with the more precise methods of recent investigation.

Several devices for determining the number of bacteria in the atmosphere have been employed. These vary from the simple expedient of exposing agar or gelatin plates to the air for a fixed period, to rather elaborate pieces of apparatus for drawing an accurately measured quantity of air through a filtering substance. The exposure of plates of nutrient media can, of course, give numerical results that are only rudely approximate. Much more definite data have been secured by employing such a device as that invented by Sedgwick and Tucker (Fig. 149).* With the aid of this apparatus it was found, for example, that in every 10 liters of the outdoor air in the city of Boston in winter there were present about ten to fifteen bacteria capable of growing on the ordinary culture-media and about half as many molds.† Winslow‡ has devised

* Twelfth Ann. Rep., Mass. State Board of Health, Boston, 1889.

† Tucker: Twelfth Ann. Rep. State Board of Health of Mass., 1889.

‡ Winslow: Science, 1908, 28, p. 28.

a simple method of enumerating bacteria in air which consists in draining a measured quantity of air through two culture bottles, on the bottom of each of which is a layer of nutrient gelatin. Flemming* has obtained samples of air high above the earth's surface by the use of balloons and has found that the air contains living germs up to an altitude of over 4000 meters, although in much smaller numbers at heights above 500 meters than below this altitude. The same observer also found that the bacterial content of the air is much lower in a period of prolonged sunshine than in cloudy weather, that it is especially large at the level of the lower cloud limits, and that chromogenic bacteria and yeasts or torulæ are noticeably abundant.

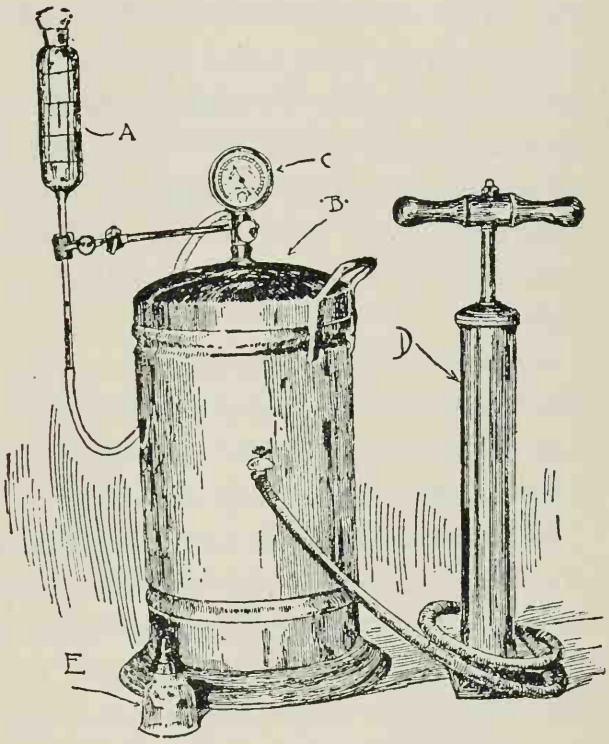

Fig. 149.—Apparatus for the quantitative determination of micro-organisms in air: *A*, Aërobioscope; *B*, air-cylinder; *C*, vacuum gauge; *D*, air-pump; *E*, glass shield (Tucker).

The kinds of micro-organisms in the air vary somewhat in different localities, but certain forms are pretty uniformly present. Molds and yeasts are quite common in the atmosphere, and in some situations outnumber the bacteria. Spore-forming bacteria, like the hay bacillus (B. subtilis), are of almost universal distribution, and from their resistance to desiccation are likely to be found in air examinations. Among the saprophytic organisms commonly met with are the common blue-green mold, Penicillium glaucum, the pigment-producing, yeast-like organism known as "red yeast," and a number of familiar bacteria, including several micrococcus and sarcina forms (Sarcina lutea, a yellow chromogen *et al.*), as well as the ubiquitous B. subtilis.

* Flemming: Zeitschr. f. Hyg., 1908, 58, p. 345.

Pathogenic micro-organisms, such as the tubercle bacillus and the pyogenic cocci, have been found in the air of hospitals and sick-rooms, but, as a rule, pathogenic bacteria in dry dust are of rare rather than frequent occurrence. Observations and experiments, especially by Flügge and his associates, have shown, however, that bacteria of various kinds may be expelled from the mouth or throat of healthy or sick persons and persist for a time in the immediate surroundings. The fact that minute droplets of moisture or mucus may be discharged into the air by coughing, sneezing, and talking, and may then float about for some time in the neighborhood of the person discharging them, seems to be the most significant result of air examination. Neither typhoid bacilli nor diphtheria bacilli have ever been found in sewer air, which, as a rule, is nearly free from bacteria of all kinds. The absence of germs from the air of sewers is to be explained in large part by the fact that the particles in a current of air passing over a moist surface tend to adhere to the surface and are not easily dislodged. For the same reason the air expired from the lungs contains fewer bacteria than the air inhaled.

Routine bacterial examination of the air of dwellings or school-rooms has not yielded and does not seem likely to yield results of much positive importance. The presence of dust particles to which bacteria chiefly adhere may be determined in simpler ways.

Bacteria in Soil.—The distribution of bacteria in the soil is naturally dependent upon the presence of organic matter, moisture, and other factors that influence development and continued vitality. More bacteria are found, for example, in manured soil than in dry sand. Houston* found uncultivated sandy soils to contain on an average 100,000 bacteria per gram, and garden soils 1,500,000, while sewage contaminated soils might harbor as many as 115,000,000. The upper six inches of the soil are richest in bacteria. Few are found in undisturbed soil below a depth of 4 to 5 feet. In sand-beds used for filtering sewage a similar vertical distribution is observed; the bacteria are most abundant in the upper layers, and very few are alive in the lower strata.

* Houston: "Report on Chemical and Bacteriological Examination of Soils," Local Gov't Bd., 1897–1898.

The supply of bacteria present in the soil is being continually renewed by the excrements of animals, by the bacteria concerned in the various fermentative and putrefactive processes occurring everywhere, and by those that are precipitated out of the air by rain. One is consequently likely to find a large variety of organisms in soil samples, the kinds found at any particular time and place being the result not only of recent additions, but of long-continued selection and adaptation. Unless contamination has been recent and extensive, certain species of bacteria usually predominate in soil. Aërobic spore-forming bacteria, like B. subtilis and allied forms, and also anaërobes, like the bacillus of malignant edema, are particularly characteristic of the normal soil flora. B. proteus (p. 382) is also very common in soil.

Certain spore-forming pathogenic bacteria are found more or less commonly in soil. Spores of the anthrax bacillus may retain their vitality and virulence in the earth for many years, and pasture-lands that are once infected with anthrax become practically unsafe for grazing cattle. As already mentioned, the whole group of pathogenic anaërobes (B. tetani, B. edematis, *et al.*) finds a congenial habitat in the soil.

Typhoid bacilli sometimes find their way into soil along with human excreta. There is evidence in this case that little or no multiplication takes place, but vitality, on the other hand, may be considerably prolonged, possibly for two or three months.* The danger from this source is worth recognizing, since soil infected with typhoid bacilli may readily be washed into a water-supply. Contamination of the water may take place more or less continuously, or only under certain unusual conditions, as after exceptionally heavy rains. The abundance of B. coli in soil is sometimes, with certain reservations, taken as an indication of the extent and recency of soil pollution. It must be borne in mind, however, that B. coli is commonly present in the intestines of many animals, and that findings must be interpreted with discrimination. Houston† has shown that B. coli and other sewage bacteria tend to disappear more or less rapidly from soil to which they are added; that, in a

* Firth and Horrocks: Brit. Med. Jour., Sept. 27, 1902.

† Houston: Rep. Local Gov. Board, 1900–1901, p. 405; 1901–1902, p. 455.

word, a process of bacterial self-purification of soils occurs. Savage* also has observed the disappearance of B. coli from "made soil."

The burial of the bodies of persons dying from infectious diseases does not, as has been sometimes surmised, tend to perpetuate pathogenic germs. Rather elaborate experiments by Lösener† and others have shown that the longevity of non-spore-bearing organisms under the ordinary conditions of earth burial is not great, a few weeks sufficing for the complete disappearance of S. choleræ, B. diphtheriæ, etc. The hygienic arguments against earth burial, therefore, do not seem to be decisive, whatever be the force of the esthetic and economic objections.

The detailed study of bacteria in soils has been pursued especially in connection with the investigation of agricultural processes. Since the chemical changes produced by bacteria depend both upon the number of organisms present and upon their physiologic activity or "virulence," methods have been devised to determine soil efficiency from these two points of view. Rémy's method‡ consists in adding weighed amounts of soil to nutrient solutions compounded in such a way as to favor the development of various kinds of bacteria, such as the nitrifying, the nitrogen-fixing, the ammonifying, etc. Hiltner and Störmer§ have attempted to place the determinations on a quantitative basis by the dilution method, using for the inoculation of special solutions constantly decreasing amounts of soil until a point is reached at which the specific physiologic action fails to appear. Löhnis,‖ by the use of Hiltner and Störmer's dilution method, found in 1 gram of soil 3,750,000 peptone-decomposing bacteria, 50,000 urea-decomposing bacteria, 50,000 denitrifying bacteria, 7500 nitrifying bacteria, and 25 nitrogen-fixing bacteria. In the same soil only 1,270,000 bacteria developed in soil-extract gelatin plates. Interesting studies have been made upon the effect of adding carbon

* Savage: Jour. of Sanit. Inst., 1903, 24, p. 442.

† Lösener: Arb. a. d. k. Ges., 1896, 12, p. 448.

‡ Rémy: Centralbl. f. Bakt., ii, 1902, 8, pp. 657, 699, 728, 761.

§ Hiltner and Störmer: Arb. a. d. k. Ges., 1903, 3, p. 445.

‖ Löhnis: Centralbl. f. Bakt., ii, 1905, 14, pp. 2, 3.

bisulfid to soils. This substance, which is a powerful germicide, seems to destroy the existing bacterial equilibrium in the soil and to open the way for an entirely new bacterial development. The change thus brought about in the relations of the different groups of soil bacteria favors in some way not wholly understood the accumulation of certain available nitrogen compounds, which are readily utilized by the higher plants.

The Bacteriology of Water.*—The bacteria in air are not under suitable conditions for multiplication, but are simply floating about in the forlorn hope, so to speak, that a chance breeze may waft them to a favorable environment; in soil the conditions for development occur only at certain times and places, and in the long run are adapted only for particular species; in water, on the other hand, a proper temperature and abundant food-supply often coexist, and permit the development of a rich and varied bacterial flora. Add to this the fact that many kinds of bacteria are washed into water from air and soil and from the living and dead bodies of plants and animals, and it is seen that almost any germ, pathogenic or saprophytic, might be occasionally or exceptionally found in water. At all events, it is clear that, large as is the number of bacteria that succeed in thriving in water, a far larger number must from time to time make their way into it, to survive there for a longer or shorter period.

The methods used to determine the number and kind of bacteria present in water have been elaborated particularly with a view to the sanitary significance of such an examination. The quantitative examination in its simplest form consists in the enumeration of colonies of bacteria developing upon plates of nutrient gelatin or agar. Specimens of water must be carefully collected in sterilized bottles with a view to avoiding contamination from the hands or other outside sources. Considerable change may take place in the bacterial content of a water during transportation, even in ice-

* Three excellent books on the bacteriology of water may be especially mentioned: W. G. Savage, "The Bacteriological Examination of Water-Supplies," London, 1906; Prescott and Winslow, "Elements of Water Bacteriology," 2d ed., New York, 1908; W. H. Horrocks, "An Introduction to the Bacteriological Examination of Water," London, 1901.

packed samples,* so that the best procedure consists in mixing the water with nutrient gelatin and plating the mixture within one hour, or preferably one-half hour, after removal of the water from its source. The Committee on Standard Methods of Water Analysis appointed by the Laboratory Section of the American Public Health Association has made the following recommendations, which fairly represent the prevailing practice in the United States:

"The standard medium for determining the number of bacteria in water shall be nutrient gelatin, as is the case in Germany and in England. For field work, and for sewage and polluted waters which cannot be plated promptly after collection, agar may be substituted. All variations from these two media shall be considered as special media. If any medium other than standard gelatin is used, this fact shall be stated in the report.

"For general work the standard reaction shall be + 1 per cent., but for long-continued work upon water from the same source the optimum reaction shall be ascertained by experiment and thereafter adhered to. If the reaction used, however, is different from the standard, it shall be so stated in the report.

"The media shall be prepared as specified on pp. 104–110.

"The use of simpler media, such as albumose and agar dissolved in distilled water, is a step in the right direction, but the evidence as to comparable results in various laboratories is still uncertain.

"*Procedure.*—Shake at least twenty-five times the bottle which contains the sample. Withdraw 1 c.c. of the sample with a sterilized pipet and deliver it into a sterilized Petri dish, 10 cm. in diameter. If there is reason to suspect that the number of bacteria is more than 200 per c.c., mix 1 c.c. of the sample with 9 c.c. of sterilized tap or distilled water. Shake twenty-five times and measure 1 c.c. of the diluted sample into a Petri dish. If a higher dilution is required, proceed in the same manner; *e. g.*, 1 c.c. of the sample to 99 c.c. of sterilized water, or 1 c.c. of the once diluted sample to 9 c.c. of sterilized water, and so on. In the case of an unknown water or a sewage, it is advisable to use several different dilutions for the same sample. To the liquid in the Petri dish add 10 c.c.† of standard gelatin at a temperature of about 30° C., or 10 c.c.† of standard agar at a temperature of about 40° C. Mix the medium and water thoroughly by tipping the dish back and forth, and spread the contents equally over the bottom of the plate. Allow the gelatin to cool rapidly on a horizontal surface and transfer to the 20° C. incubator as soon as it is hard. Incubate the culture for forty-eight hours at a temperature of 20° C. in a dark, well-ventilated incubator where the atmosphere is practically saturated with moisture. After this period of incubation place the Petri dish on a glass plate suitably ruled and count the colonies with the aid of a lens which magnifies at least five diameters. So far as practicable, the number of colonies upon the plate shall not be allowed to exceed two hundred. The whole number of colonies upon the plate shall be counted, the practice of counting a fractional part being resorted to only in case of necessity.

* Jordan and Irons: Reports and Papers of Amer. Pub. Health Asso., 1889, 25, p. 564.

† Many observers obtain more consistent results with the use of 6 c.c.

"When agar is used for plating, it will be found advantageous to use Petri dishes with porous earthenware covers in order to avoid the spreading of colonies by the water of condensation.

"*Expression of Results.*—In order to avoid fictitious accuracy and yet express the numerical results by a method consistent with the precision of the work, the rules given below shall be followed:

NUMBER OF BACTERIA PER CUBIC CENTIMETER:

From	1	to	50	Recorded as found		
"	51	"	100	"	to the nearest	5
"	101	"	250	"	"	10
"	251	"	500	"	"	25
"	501	"	1,000	"	"	50
"	1,001	"	10,000	"	"	100
"	10,001	"	50,000	"	"	500
"	50,001	"	100,000	"	"	1,000
"	100,001	"	500,000	"	"	10,000
"	500,001	"	1,000,000	"	"	50,000
"	1,000,000	"	10,000,000	"	"	100,000

"Note: The determination of the number of bacteria which develop as 20° C. under anaërobic conditions, the number which develop at 37° C., the number of red colonies which develop on a lactose-litmus-agar plate, and the number which develop on media other than the standard are not advised at regular procedure for the special determinations for either water or sewage. B. coli determinations are more valuable; species determinations may also be useful. No uniform methods of procedure for the special determinations above listed are here given, as the value of their determination depends upon the individuality of local conditions for each problem."

The results obtained by the use of quantitative methods are in all cases relative and approximate rather than absolute and exact. Certain bacteria, such as the strict anaërobes, do not grow under the conditions in which the plates are incubated, and others, like the nitrifying organisms, have peculiar nutritional requirements and do not develop on the ordinary media.

Nevertheless the "colony counts" or "numbers of bacteria" reported by different observers are in some degree comparable, especially when "standard" methods are employed.

As might be supposed on *a priori* grounds, very large numbers of bacteria are found in sewage and sewage-polluted waters, whereas very few occur in the water of most springs or deep wells. River-water contains, as a rule, more bacteria than lake- or pond-water, the difference being due in part at least to the sedimentation that occurs in quiet waters. The following table includes some representative determinations of the number of bacteria in water:

Source.	Number of Colonies per Cubic Centimeter.	Authority.
Thames River	277 (Apr.)–2075 (Jan.)	Houston.
Illinois River at Ottawa (about 55 miles below mouth of Chicago Drainage Canal)	6300–8200 (May)	Jordan.
Potomac River	750 (May)–11,500 (Mar.)	Longley.
Mississippi River at New Orleans	805 (Aug.)–3597 (Apr.)	Weston.
Loch Katrine	74	Frankland.
Lake of Lucerne	8–51	Frankland.
Lake Michigan near Chicago	68–2000	Jordan.
Deep well-waters	0–12	Prescott and Winslow.
Spring-water (av. of 54 samples)	41	Mass. State Bd. of Health.
Sewage (Boston)	712,000 (Dec.)–11,487,500 (Sept.)	Winslow.

The degree of sanitary significance attaching to such data has been the subject of some difference of opinion and some confusion. The belief is widespread among the general public that the sanitary character of a water can be estimated pretty directly by the number of bacteria it contains. Taken by itself, however, it must be admitted that the number of colonies which develop when a given sample of water is plated affords no secure basis for judging its potability. A pure spring-water containing at the outset less than 100 bacteria per cubic centimeter may come to contain tens of thousands per cubic centimeter within twenty-four to forty-eight hours, after standing in a clean glass flask at a fairly low temperature. There is no reason for supposing that the wholesomeness of the water has been impaired in any degree by this multiplication of bacteria.

As a matter of fact, like the sanitary chemical analysis of water, the quantitative bacterial analysis has only an empirical value. Experience in a broad way has shown that most natural waters known to be pure contain relatively few bacteria capable of developing by the usual methods, whereas sewage and sewage-polluted waters contain large numbers. Some observers of wide experience are inclined to hold that natural waters, which are found by approved methods to contain more than 1000 bacteria per cubic centimeter,

should be regarded as distinctly suspicious. A turbid river-water, however, may be relatively unpolluted, and yet at times contain several thousand bacteria per cubic centimeter.

It has been shown in the chapters on typhoid fever and cholera that the epidemiologic evidence connecting the use of sewage-polluted water with the causation of specific disease is of a very definite and cogent character. At the time when methods for the bacterial examination of water first came into use it was confidently expected that with their aid it would be possible to discover the presence of specific pathogenic bacteria, and so obtain more or less precise information as to the wholesomeness of a water. These expectations have never been realized, partly because of the great difficulty, in spite of the invention of many ingenious methods, in picking out specific micro-organisms from among immense numbers of sewage bacteria, partly because the life of the typhoid bacillus and the cholera spirillum in water is short, and examination of a water known to have dealt disease or suspected of having done so is often so long delayed that any disease germs that may have been originally present have perished. For these reasons the search for specific pathogenic bacteria in water is rarely crowned with success, and their real or apparent absence affords no good ground for judging the general safeness of the water examined. As pointed out above, the actual number of bacteria in a water is also no absolute criterion of wholesomeness, although, taken together with other factors concerning the source and history of the water, it may prove of service in forming an opinion.

The practical failure of colony enumeration and of the search for specific disease germs to disclose important sanitary relations has led to other attempts to correlate the bacterial content of a water with its sanitary quality. The most widely used and, by general consensus, the most valuable of these tests is the "colon test." This is based upon the circumstance that the colon bacillus, B. coli, is a common inhabitant of the human intestine, and is found in great abundance in sewage.* Its close biological relationship to the typhoid bacillus and the fact that like the latter organism it finds its way into sewage chiefly from the discharges of the human

* As many as 100,000 per cubic centimeter in fresh sewage.

body render its presence, especially when in large numbers, peculiarly suggestive.

Two methods for the quantitative determination of B. coli in water are in common use. Each has some advantages. Following the Report of the Committee on Standard Methods, these methods may be designated as Procedures A and B.

Procedure A: "This method is most applicable for sewages and polluted waters in which B. coli is present in one c.c. or less." Nutrient agar to which sugar (1 per cent. dextrose) or lactose and litmus (1 per cent. of an aqueous solution of azolitmin) are added, is the medium employed. Measured quantities of water, if necessary suitably diluted with sterile water,* are mixed with this, poured into Petri dishes with porous earthenware covers, and incubated at 40° C. for twelve to twenty-four hours. "If no red colonies or gas-producing colonies appear, then B. coli is considered absent in the volume of the sample tested." When colonies resembling B. coli are found, several (at least five) are selected for further detailed study and examined, according to the recommendation of the Committee, for the following characters: morphology, motility, non-liquefaction of gelatin, fermentation of dextrose broth, coagulation of milk, indol production, reduction of nitrates. It is probable, however, that the last two tests have little diagnostic value.

Procedure B: "This method is most applicable for waters requiring one or more c.c. to be tested for a positive result." Accurately measured quantities of water are placed in fermentation tubes containing sugar broth (1 per cent. dextrose) and incubated at 40° C., the presence of gas being noted twice a day. Absence of gas formation at the end of forty-eight hours is taken as indicating the absence of B. coli. As soon as any gas is formed (usually in sixteen to twenty-four hours) litmus-lactose-agar plates are made from the sediment at the bottom of the closed arm and diagnostic tests carried out with pure cultures as under Procedure A. Quantitative data are obtained by a simple calculation. If ten tubes are inoculated in the manner described, each with 0.1 c.c. of water, and the colon bacillus is found in seven of these, the inference is that there are seven colon bacilli in 1 c.c. of the water ex-

* For example, 1 c.c., 1 c.c. of a mixture of 1 : 10, 1 : 100, etc.

amined. This fermentation tube method was devised by Theobald Smith in 1892,* and has proved a delicate and highly satisfactory means of determining the relative abundance of B. coli.

"Presumptive tests," that is, tests, for example, based upon inferences from amount and kind of gas production observed when water is directly inoculated into fermentation tubes, rather than upon detailed examination of pure cultures, have been used to advantage by some investigators in handling large numbers of samples, and undoubtedly furnish information of a valuable, if not entirely precise, nature. A presumptive test introduced by Jackson† has won especial favor among students of the bacteriology of water. This consists in the use, in place of dextrose broth, of sterilized, undiluted fresh ox-bile containing 1 per cent. of lactose and 1 per cent. of peptone. The selective inhibitory action of the bile salts, previously observed by MacConkey, greatly facilitates the determination of the presence of Bacillus coli. The method has proved valuable especially in the examination of highly contaminated waters.‡ In ordinary water examination, however, the use of a more exact procedure is desirable, if not indispensable.

The interpretation of the results of the colon test is a matter on which there is now general agreement. It must be remembered that the relative abundance, rather than the presence of colon bacilli, is the essential feature of this test. The discovery of one colon bacillus in 50 c.c. of a water or even occasionally in 5 c.c. affords no reasonable ground for casting suspicion upon the character of the water. The possibility of sporadic contamination with colon bacilli derived, not from man, but from domestic animals or birds, must always be kept in mind. Manured fields and pastures filled with grazing cattle or sheep are likely sources of colon bacilli, and may give rise to mistaken inferences if the environmental examination of a water-supply is neglected. Considerable numbers of colon bacilli in a water, however, are always suggestive of marked fecal contamination by man or animals. Those who have had most experience in the application and interpretation of this test are of opinion that a water showing the presence of B. coli invariably, or

* Smith, Theobald: The Wilder Quarter Century Book, 1893, p. 227.

† Jackson: Biol. Studies by the Pupils of W. T. Sedgwick, Boston, 1906.

‡ Sawin: Suppl. No. 3, Jour. Infect. Dis., 1907, p. 33.

quite constantly in each cubic centimeter, is, to say the least, of extremely doubtful quality.

General reliance upon the principle of the colon test has led in recent years to its widespread application. It is not only almost invariably employed in the routine examinations of water from suspected sources, but has also been resorted to for the study of special problems, such as the efficiency of sand filters,* the self-purification of streams,† and the pollution of oyster-beds.‡ On the whole, it is felt by water analysts that greater weight can be attached to the results of the colon test in the hands of an experienced observer than to any other isolated determination, bacterial or chemical.

Some attempts have been made to discover other organisms besides B. coli that are equally indicative or more indicative of sewage contamination. Streptococci, for example, have been supposed by some observers to show that recent and hence specially objectionable pollution has occurred, but the weight of available evidence is against this view. The longevity of streptococci in water is sometimes greater, sometimes less, than that of colon bacilli. The lack of suitable differential characters in the group of streptococci renders the use of these organisms as an index of sewage pollution a procedure of doubtful value.

Among other bacteria found frequently in sewage and polluted water may be mentioned the Proteus group (p. 382), B. cloacæ (p. 383), B. welchii (p. 326), and B. subtilis (p. 227). These forms occur also in pure water, but much less commonly. A host of different microbes have been described as inhabiting uncontaminated water; one of the most common and abundant of these is B. fluorescens liquefaciens, an organism resembling B. pyocyaneus in nearly all respects except in the production of a blue pigment.

The great majority of bacteria in water are killed by freezing, hence ice always contains but a fraction of the number in the water

* Thirtieth and Thirty-first Rep., Mass. State Bd. of Health Rep., 1898, 1899.

† Jordan: Jour. Exper. Med., 1900, 5, p. 271.

‡ Klein, E.: Report of Experiments and Observations on the Vitality of the Bacillus of Typhoid Fever and of Sewage Microbes in Oysters and other Shell-fish. London, 1905.

from which it was formed. Over 90 per cent. both of the ordinary water bacteria and of typhoid bacilli die within a few hours, and a progressive decline in numbers then takes place, less than 1 per cent. of typhoid bacilli surviving at the end of a week of freezing, according to experiments. Ice stored for six months is practically sterile. Outbreaks of typhoid fever have rarely been traced to the use of ice, although in at least one case the evidence of ice-transmission seems quite conclusive.* Danger of typhoid infection from the use of ice in drinking-water is always less than from the use of water from the same source.

When by bacterial examination or otherwise a water is known to be unsafe for consumption, the question arises as to ways and means of artificial purification. There are a number of useful methods of purifying water, differing according to the amount and

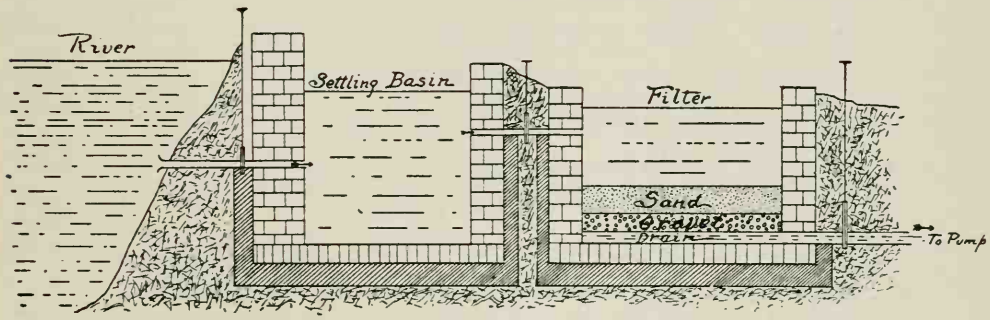

Fig. 150.—Cross-section of filter plant (after Hazen).

character of the water to be treated. Large public water-supplies in Europe are commonly purified by sand-filtration. The sand filters are constructed so that the water passes through from 1 to 5 feet of sand supported upon carefully graded layers of gravel (Fig. 150). The rate of filtration must be accurately regulated, and the efficiency of operation controlled by frequent bacterial tests of the effluent.† Such filters are now in operation in Lawrence, Mass., Albany, N.Y., Washington, D. C., Philadelphia, Pa., and other cities in the United States. At Lawrence water pumped from the Merrimac River is applied to the filters; the river-water contained in 1905 an average of 12,700 bacteria per cubic centimeter, and the effluent from the filters only 70, while the percentage of 1 c.c. sam-

* Hutchings and Wheeler: Amer. Jour. Med. Sci., 1903, 126, p. 680.

† Thirtieth and Thirty-first Rep., Mass. State Bd. of Health, 1898, 1899.

ples containing B. coli was diminished from 100 per cent, in the raw water to 4.7 per cent. in the filtered water. The real sanitary efficiency of the filtering process is further attested by the typhoid fever death-rate in Lawrence, which has sunk from an average of 9.24 in the fourteen years before the filter was installed to an average of 3.02 in the years 1894 to 1904.

Highly turbid waters, such as those of the Mississippi, Ohio, Missouri, and other western rivers, require to be clarified as well as purified. So-called "mechanical" filters are often used where a simple sand filter could not yield a clear effluent, or would become quickly clogged. The mechanical filters, of which there are many, require for their operation the use of a coagulant. Either sulfate of aluminum or ferric sulfate is commonly employed for this purpose. On the addition of the coagulant to the water, a flocculent precipitate is formed which carries down with it a large part of the suspended matter. When properly managed, a high degree of bacterial efficiency may be reached with mechanical filters. They have the advantage of being able to treat a large quantity of water upon a relatively small filtering area, and also of removing minute particles of clay which the ordinary sand filter allows to pass. A combination of the use of a coagulant with the hygienically efficient sand filters has been recommended for use in some localities where high turbidity prevails only during certain periods.

Other methods of purifying water on a large scale are in use to a limited extent. One of the most promising of these is the treatment of water with ozone,* which has given highly satisfactory results in several localities, although the relatively high expense of chemical treatment of very large quantities of water renders the immediate general adoption of such systems rather unlikely.

When, as is too often the case, a public supply is known to be impure, domestic or house filters are often resorted to. Many of the articles sold as filters or water purifiers have little sanitary value, and at most remove excessive color or turbidity from the water without materially increasing its safety. Certain kinds of small filters are attached directly to the tap, and the water is filtered under pressure; others are simple gravity filters on which the water is poured and through which it percolates slowly. The principle

* Weyl: Centralbl. f. Bakt., 1899, 34, p. 15.

underlying the operation of all the best house filters operated under pressure is essentially the same; namely, straining out of the bacteria. Since bacteria can pass freely through a thin layer of loose or coarse material, only those filters made of exceedingly compact material can achieve the end desired. Among the best-known filters of this class are the Pasteur-Chamberland (baked clay) and the Berkefeld (infusorial earth). Both of these have been repeatedly demonstrated to be efficient when operated under the conditions obtaining in a bacteriologic laboratory, and yield sterile effluents, the Berkefeld for several days, the Pasteur-Chamberland for somewhat longer. Under actual working conditions in the household and elsewhere, the use of the compact filters not infrequently presents certain difficulties. The yield of these filters, particularly and necessarily of the more efficient types, is always scanty, and if the details of connection and cleansing are intrusted to unskilled or negligent hands, the filter may become entirely useless. A good deal of time and care are needed to insure that a battery of these tubes in a large school or factory is kept continually in good working order. Daily inspection by competent and trustworthy persons is indispensable, and bacterial tests should be made at frequent intervals.

"It might be thought that nowadays most people understood the proper use of filters on the Pasteur principle; it has, however, been found that in regimental soda-water factories in India (managed and supervised by regimental officers), where the water was known to be dangerous and in need of efficient filtration, the filter *bougies* have been fixed in such a way as to permit of the water passing through the joint, instead of through the wall of the bougie; this being done in order to get a more rapid flow. . . . .

"During fifteen years a large number of filters have been used in barracks and hospitals; they have proved to be wonderfully serviceable. But they require minute attention; and every fortnight taking to pieces, cleaning, inspection, replacement of perhaps 150 fragile tubes and receptacles. In default of such attention, the filters rapidly become useless or even dangerous.

"Sterilization by heat is a recent invention. The apparatus employed has already produced excellent results, and is very favorably regarded. Pathogenic germs are absolutely destroyed and the

sterilizing power is not subject to such limitations as that of filters which are liable to become dirty and obstructed, as well as to cracks and breakage. The action of the sterilizers is continuous, night and day, and requires very little supervision; only a few are needful, and they can be satisfactorily cleaned every two or three months in a few hours by an armorer's assistant."*

Gravity or low-pressure house filters with a 12-inch sand layer may be constructed on the same principle as the large sand filters above described; when properly operated, they constitute a considerable safeguard. Animal charcoal, by removing color, gives brilliancy to the water, but is not in other respects suitable for a filtering substance.

At all times the safest method of purifying water is by boiling. It is not necessary to render the water sterile, that is, free it altogether from the spores of the hay bacillus or other harmless organisms. Boiling for five minutes is quite sufficient to destroy with certainty the typhoid bacillus and allied forms, as well as the cholera spirillum. Anthrax infection by way of drinking-water, although theoretically possible, is so rare as to be practically unknown; even anthrax spores, however, are killed by ten minutes' boiling. The flat taste of freshly boiled water may be removed by pouring the water a few times back and forth from one vessel to another, or by passing it through an inexpensive sand or sandstone gravity filter, which also removes the larger suspended particles. When water-borne disease is prevalent, or when a water-supply is notoriously impure or exposed to chance of infection, boiling is the only wholly safe procedure.

* Jour. Roy. Army Med. Corps, 1904, 2, pp. 706, 751.

CHAPTER XXXV

THE BACTERIAL DISEASES OF PLANTS

Although the diseases of plants demonstrated to be caused by bacteria are perhaps not so numerous as those of animals, there can be no doubt that bacteria play a much more important part in plant pathology than was at one time supposed. It seems likely that there are many bacterial infections still unrecognized. Only a few of the better known plant diseases can be considered here.

Pear Blight (Bacillus amylovorus).—In 1880 Burrill* found a motile bacillus constantly present in the freshly blighted twigs of pear trees. No trace of fungus growth was present in the infected region, and the bacillus was always found pushing into the sound tissues in advance of visible browning and death. Inoculations made with material taken directly from diseased tissues produced the blight in healthy fruit trees. Later experiments made by Arthur and by Waite,† using more modern methods, have confirmed the essential features of Burrill's work. Pure cultures of B. amylovorus inoculated by means of delicate needle punctures into young shoots almost always produce the disease in the inoculated trees, while uninoculated trees in the neighborhood remain healthy. Waite has isolated B. amylovorus from the mouth parts of bees that had visited blighting pear flowers, has observed bees pass from such flowers to healthy ones, and blight subsequently appear in the latter. Pear blossoms protected by mosquito netting remain free from blight, while those exposed to insect visits become infected. Apparently under natural conditions the disease is never disseminated except by insect agency.

B. amylovorus possesses, according to Waite,‡ the following characteristics: It is a motile, non-capsulated bacillus, about 0.6 μ to 0.8 μ in diameter, and from 1 μ to 6 μ in length. The flagella are

* Burrill: Proc. Am. Assoc. Adv. Sci., 1880, 29, p. 583.

† See Smith, E. F.: Centralbl. f. Bakt., ii, 1899, 5, p. 810.

‡ Waite: Science, N. S., 1898, 8, p. 692.

disposed peritrichally. In broth a marked turbidity is produced and a delicate pellicle is formed which finally breaks up and sinks. Gelatin is liquefied, although not with great rapidity. Upon agar, potato, and other solid media the color of the growth is milky white. Acid is produced in various carbohydrate solutions, more vigorously with maltose than with saccharose, dextrose, or levulose. No gas is formed in the fermentation tube. Starch is not fermented. No pigment is formed and the cultures emit no odor.

The Wilt Disease (Bacillus tracheiphilus*).—Cucumbers,

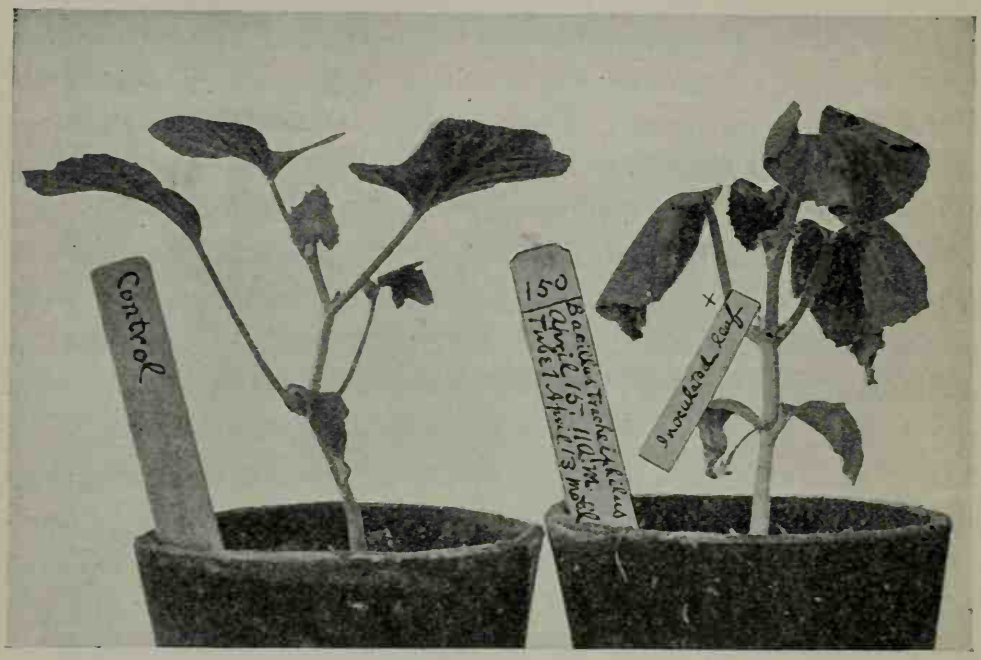

Fig. 151.—Muskmelon plant inoculated with a pure culture of B. tracheiphilus (Erwin F. Smith).

muskmelons, pumpkins, and squashes are liable to a disease characterized by the wilting of the vines, followed by shriveling and death (Fig. 151). It is caused by a bacillus whose growth fills up the water-ducts or tracheæ with a white, viscid mass. If a cucumber leaf is lightly pricked with a needle dipped in a pure culture of B. tracheiphilus, the bacteria make their way down the petiole of the leaf into the stem, where enormous multiplication occurs in the water-ducts. The first signs of the disease occur usually after about a week and always first on the inoculated leaf. In nature the

* Smith, Erwin F.: Centralbl. f. Bakt., 1895, 1, p. 364.

disease appears to be spread mainly, if not solely, through the wounds inflicted by insects, such as the striped cucumber beetle and the common squash bug. Erwin Smith has produced the disease by allowing these insects to feed on diseased vines and subsequently on healthy ones; this observer has never seen the disease escape to control plants during greenhouse experiments, except through the exclusive agency of insects as disseminators.

B. tracheiphilus grows in culture-media, but is a sensitive species. Upon agar a white, extremely viscid growth is produced. In milk no visible change occurs. The growth on potato resembles that of the typhoid bacillus. Acid is formed from glucose and saccharose. The optimum temperature for development is between 20° and 30° C.; no growth takes place at 37° C. Gelatin is not liquefied.

Brown Rot of Tomato, Egg Plant, and Potato (Bacillus solanacearum*).—A disease which affects a number of solanaceous plants and is somewhat similar to the cucumber wilt in its general symptoms, *i. e.*, wilting, is due to a different micro-organism. After a premonitory wilting of one or more shoots, the stem, especially in young plants, shrivels and finally changes to brown or black. The vessels of the affected vascular bundles are filled with myriads of bacilli. In the potato plant the bacilli spread by way of the vascular bundles to the tubers, which are attacked and destroyed. Smith and others believe that a large part of the common potato rot of the northern United States is due to this bacterial infection. In this disease, as in the cucumber wilt and pear blight, the part played by insects in the rôle of bacillus-carriers seems to be of the first importance. Experiments made with potato beetles show that when the insects are fed on diseased plants, they become capable of transmitting the rot to healthy ones. It seems possible that other leaf-eating insects may be the means of transmitting the disease.

Bacillus solanacearum grows on the ordinary culture-media with formation of a brown pigment which discolors the substratum. The growth is not viscid or only slightly so. Gelatin is not liquefied. Acid is not formed from any of the sugars. The fat of milk

* Smith, Erwin F.: Bull. No. 12, Div. of Veg. Physiol. and Path., U. S. Dept. of Agricul., 1896.

is dissolved and the medium becomes strongly alkaline and translucent. The bacillus grows well at 37° C. The micro-organism is not pathogenic for the cucurbitaceous plants, and, conversely, attempts to infect the potato and tomato with the bacillus of cucumber wilt (B. tracheiphilus) have given negative results.

A serious disease of the tobacco plant in Florida and North Carolina (Granville wilt of Stevens and Sackett) is caused by the same organism (Smith). In this case infection probably first occurs in the root. Observations in Sumatra indicate that land infected with nematodes which attack the root or base of the plant stem is particularly subject to the disease, so that the bacteria are probably brought into contact with the plant tissues through the agency of these parasitic worms. Tomato plants can be successfully inoculated with the micro-organism of tobacco wilt and vice versâ. Plants of one species grown in soil previously occupied by affected plants of another species of the same family also contract the disease.

The Basal Stem-rot of Potato (Bacillus phytophthorus*).— We are indebted to Otto Appel, of Berlin, for our first exact knowledge of this disease. In the United States Appel's work has been repeated and confirmed by Smith.† The stems of the potato rot off at the surface of the earth; the tubers are rotted in the earth and also subsequently in storage. Often tubers which appear to be sound or nearly sound externally are badly rotted internally. This disease is widely prevalent in the United States and in Europe. It is much less a vascular disease than the preceding.

The organism causing it is a white, peritrichiate bacillus, having the following characteristics (Smith): Clouds bouillon very rapidly at 30° C.; on thin sown gelatin plates, large circular colonies, gelatin is slowly liquefied; does not stain by Gram; does not produce indol; no gas from potato juice, or Witte's peptone in water with grape-sugar or cane-sugar; reddens litmus milk, and throws down a pleasant-smelling curd after five or six days; does not grow in Cohn's Solution; potato starch not much acted

* Appel, Otto: "Untersuchungen ü. d. Schwarzbeingkeit, etc.," Arb. Bio. Abt. K. G. Amt., Berlin, 1903.

† Smith, Erwin F.: "Description of Bacillus phytophthorus," Proc. 1st Ann. Meeting Am. Phytopathological Society, Boston, Dec., 1909. *Science.*

upon; reduces nitrates; streaked on sterile raw potato from agar there is prompt growth along the line of the needle (twenty-four hours or less), with a brown stain and rapid disintegration and decay of the tissues. All varieties are subject to the disease, but some to a much greater extent than others.

The Black Rot of Cabbage and Allied Plants (Bacillus campestris).—The chief diagnostic character of this disease is the blackening of the fibrovascular bundles, which may be readily observed in the stem and leaf-stalks. There is an accompanying decrease in the water-flow, and the lower leaves of the cabbage wilt, turn brown, and drop off. Rutabagas and turnips are also attacked by the same disease, but not so seriously as are some of the other members of the cabbage family. The micro-organism of the cabbage rot was first discovered by Pammel* in diseased Swedish turnips or rutabagas, and it has been more fully studied and its etiologic relations to the disease of cabbage and cauliflower established by Russell† and by Smith.‡ The disease is widely spread throughout the United States and is also common in Europe.§ Infection of the plant may take place from the soil when the roots are injured at the time of transplanting, exposing the ends of the fibrovascular bundles, or it may occur from the bite of insects. There is evidence also that a common, perhaps the usual, mode of infection is through the water-pores at the margin of the leaves. The fluid which is exuded from these pores under favorable atmospheric conditions has been shown to be an excellent medium for bacterial growth, and the

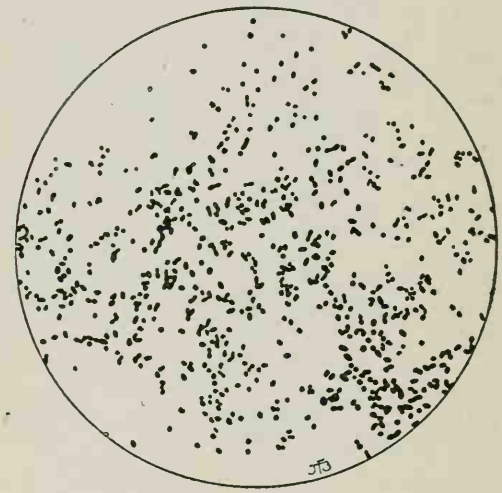

Fig. 152.—Bacillus campestris. Cover-glass (smear) preparation from the vessels of a cabbage plant received from Racine, Wis. Stained with carbolfuchsin. Drawn from a microphotograph. × 1000 (Erwin Smith).

* Pammel: Bull. No. 27, Iowa Agr. Expt. Sta., 1895, p. 130.

† Russell: Bull. No. 65, Wisc. Agr. Expt. Sta., 1898.

‡ Smith: Centralbl. f. Bakt., ii, 1897, 3, p. 284.

§ Harding: Centralbl. f. Bakt., ii, 1900, 6, p. 305.

pores offer a ready means of ingress. The fluid may become infected by the visits of slugs or various insects or may be seeded with bacilli borne to the leaf by air-currents. The precise methods of dissemination from plant to plant have not been fully determined. In other bacterial infections the bacteria appear to enter the leaf through the stomata (Fig. 154).

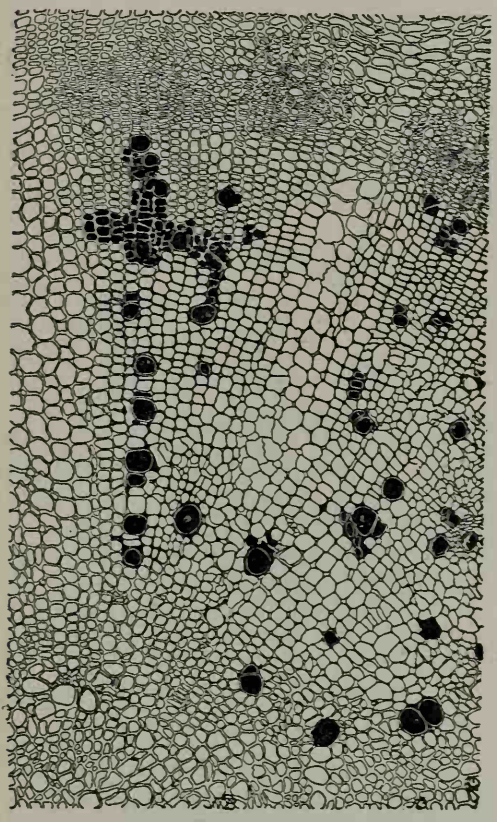

Fig. 153.—Cross-section of a turnip root, showing vessels occupied by Bacillus campestris as the result of a pure culture inoculation by means of needle pricks on the leaves. The bacteria are confined to the vessels and their immediate vicinity. They do not occur in the phloem, a small portion of which is shown at the top of the picture. Drawn from a microphotograph. × 57 (Erwin Smith).

The bacillus of black rot, B. campestris, is a short, motile, Gram-negative bacillus with rounded ends. It grows readily in the ordinary culture-media, the optimum temperature being about 25° to 30° C. Gelatin is slowly liquefied and the casein in milk is gradually digested. In solutions of the various carbohydrates that have been tested no acid is formed. Upon potato a characteristic yellow pigment, perhaps a lipochrome, is produced, which is at first of a rather light color, but becomes darker with age. Inoculations of cabbages, cauliflowers, turnips, and other plants with pure cultures of B. campestris have reproduced the typical and characteristic disease. Part of the injury done to the turnip root consists in the destruction of the cell wall, which is probably brought about by the solvent action of a cytolytic enzyme.* There is prompt action on potato starch.

The Yellow Disease of Hyacinths (Bacillus hyacinthi).—A

* Smith: Bull. No. 25, Bureau of Plant Industry, U. S. Dept. of Agr., 1903.

disease of hyacinths studied by Wakker * and by Smith † is due to a bacillus closely related to B. campestris. The disease is manifested to the naked eye by a yellow striping of the leaves, which appears, as a rule, in long narrow areas separated by tracts of green tissue. The infection spreads to the bulb, which becomes filled

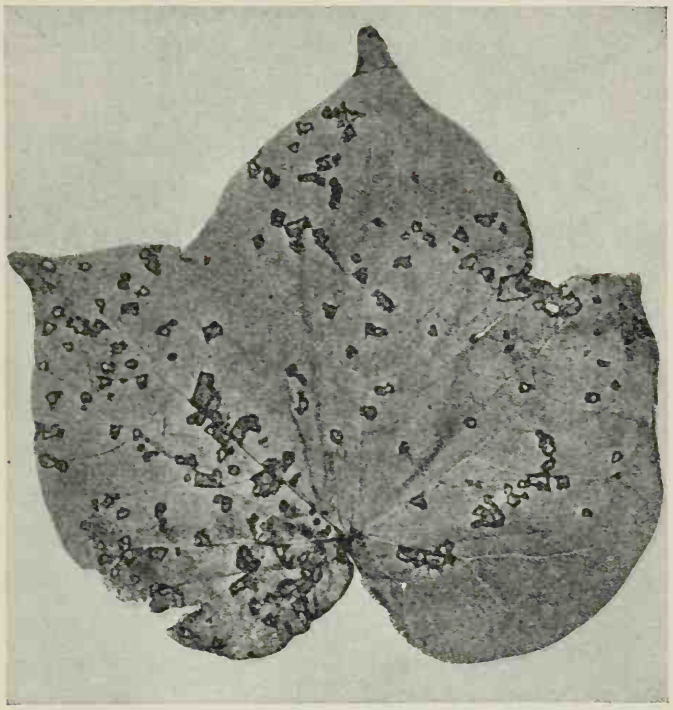

Fig. 154.—Angular leaf spot of cotton in which stomatal infections appear to be the rule. This leaf represents the secondary stage of a natural infection, *i. e.*, the spots are browned and shriveled and they involve the entire thickness of the leaf. In an earlier stage of the disease the spots are limited to the under side of the leaf (mesophyll), and occur in the form of small water-soaked areas surrounding the stomata, under which nests of bacteria occur. These spots gradually deepen so as to involve the palisade tissue, and then they become visible on the upper surface of the leaf. The spots are not yet shriveled or browned, but if the leaf is held up and viewed by transmitted light, they appear as translucent areas, while by reflected light they are dull and wet looking. A little later they present the appearance shown in this figure. All stages of this disease have been obtained by spraying upon the plants young agar cultures of Bacterium malvacearum suspended in sterile water (Erwin Smith).

with a bright yellow slime. Multiplication of the bacillus takes place chiefly in the vascular system; the walls of the vessels are destroyed, and large cavities formed in fibrovascular bundles. Some

* Wakker: Bot. Centralbl., 1883, 14, p. 315; Arch. neérland. d. sc. ex. et nat., 1889, 23, p. 1.

† Smith: Bull. No. 26, Div. of Veg. Physiol. and Path., U. S. Dept. of Agr., 1901.

destruction of parenchyma occurs, but this takes place very slowly, the disease being restricted for a long time to the bundles first invaded. In fact, one of the noteworthy peculiarities of the yellow disease is its very slow progress, the host plant not being killed for a year or more. The disease is readily induced by wounds, and pricking experiments made with needles dipped in pure cultures have given positive results. Daughter bulbs contract the disease from mother bulbs. Perhaps insects that visit the blossoms or eat the leaves play some part in spreading infection. Wakker

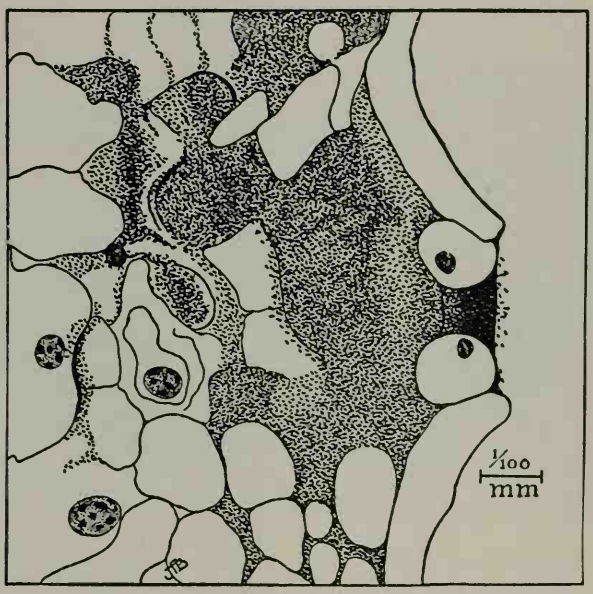

Fig. 155.—Bacterium stewarti filling the substomatic chamber and pushing out into the deeper tissues of a maize leaf. The result of an inoculation made by placing a small quantity of a pure culture on the tip of a sweet-corn leaf in the seedling stage. The globose bodies are nuclei (Erwin Smith).

believed the disease to be often transmitted by knives used in cutting diseased plants.

B. hyacinthi is a small, motile, chromogenic bacillus which grows well on the ordinary culture-media. Gelatin and blood-serum are slowly liquefied. Yellow pigment is produced on most media and in the tissues of the host plant. Acid but no gas is formed in dextrose and saccharose broth. Milk is rendered alkaline and the casein is precipitated. Indol is formed in peptone solution. The optimum temperature is about 28° to 30° C.; growth does not occurs at 37° C. There is very slight action on potato starch.

According to Erwin F. Smith, B. hyacinthi, B. campestris, B.

phaseoli (parasitic on beans), and B. stewarti (Fig. 155). (parasitic on corn, especially sweet corn) constitute a natural group. They are all bacilli with a single polar flagellum. All produce a yellow or brown pigment and live parasitically or semiparasitically on various plants. Cultural characters show a resemblance in many important particulars.

Another disease of hyacinths, characterized by a rapid, soft rot of the bulb, has been attributed by Heinz* to infection with a micro-

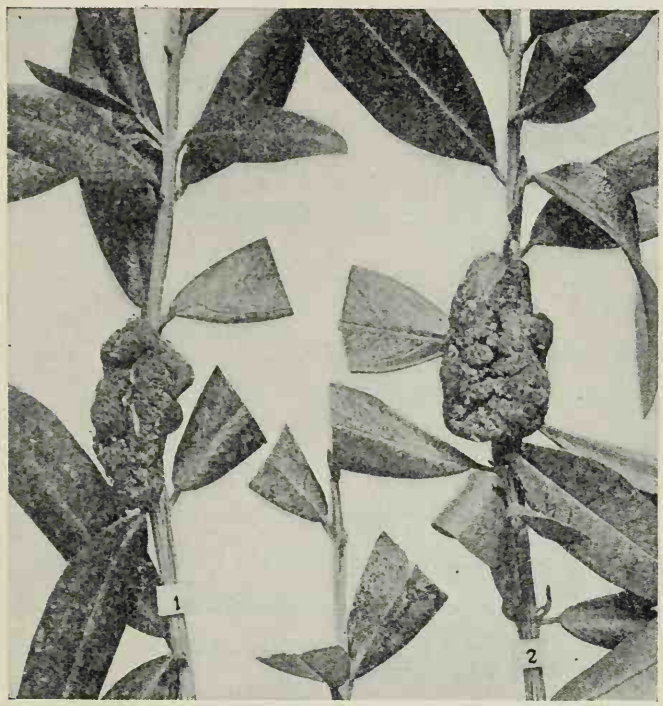

Fig. 156.—Bacterial olive-knots produced by needle-pricks of a pure culture. Inoculated January 4th; photographed May 16th. The organism came originally from an olive-knot obtained in California, where the disease has been very destructive (Erwin Smith).

organism which he has called B. hyacinthi septicus. The disease is a bad-smelling, soft, wet rot which involves all the tissues in a general slimy decomposition and destroys the plant in a few days. Heinz was able to reproduce the disease by inoculation with pure cultures, marked symptoms of rot appearing within twenty-four hours in the leaves and bulbs of hyacinths and onions. The bacillus is actively motile, gives an unpigmented growth, and is said to be rather tolerant of acids.

* Heinz: Centralbl. f. Bakt., 1899, 5, p. 535.

Olive-knot (Bact. savastanoi = Bacillus oleæ in part).— Savastano in 1886–1887 found a cultivable bacillus constantly present in the interior of young, growing olive galls.* Later he succeeded in infecting healthy plants with pure cultures of the bacillus and in practically establishing the etiologic relation of the micro-organism to the disease. The olive-knot has appeared on the trees of certain olive groves in California, where it seems to be due to the same bacillus described by Savastano. From this source it has been especially studied by Smith, who has cleared away much of the confusion caused by the use of mixed cultures and organisms of mistaken identity by other observers.† Smith's work has been thoroughly controlled by inoculation experiments (Fig. 156). The genuine olive-tubercle organism produces a whitish growth on various culture-media, does not liquefy gelatin, ferments dextrose, but not lactose, and produces abundant alkali in litmus milk. It is actively motile, strongly aërobic, and forms no spores. The interesting fact that tumors can occur by metastasis was discovered by Schiff-Giorgini, and has been confirmed experimentally by Smith, using pure cultures. The primary tubercles, which are due to external infection, begin in the cortex. From the point of infection the bacteria make their way to distant points by way of the vascular system. The secondary tumors begin deep in the tissues at the junction of wood and pith.

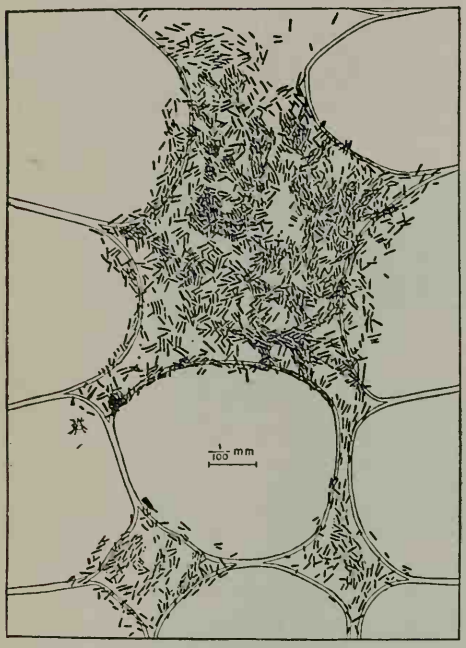

Fig. 157.—B. carotovorus wedging apart cells of the carrot. Drawn mostly from one plane. In placing the cover-glass a few of the bacteria have been crowded out of the intercellular spaces into parts they did not originally occupy. × 500 (Erwin Smith).

* Savastano: C. R. de l'Acad. d. sc., 1886, 103, p. 1144.

† Smith: Bull. No. 131, Bureau of Plant Industry, U. S. Dept. of Agriculture, 1908.

Other Plant Tumors of Bacterial Origin.*—Smith and Townsend have described under the name Bacillus tumefaciens an organism which was found in galls or tumors occurring naturally on the cultivated marguerite. It is a motile, aërobic bacillus, which grows on the ordinary culture-media. It does not liquefy gelatin or acidify milk, and in other respects resembles somewhat Bacillus oleæ. It does not, however, infect olive shoots. The gall-producing power of Bacillus tumefaciens is not restricted to one host-plant. Various species representing many different families have been artificially infected with pure cultures of this organism. Perhaps, economically speaking, its most important activity is the production of the dreaded crown-gall of peach trees.

Additional Considerations.—In the preceding pages many instances have been given of the frequent conveyance of bacterial plant diseases by biting insects. The question whether bacteria can penetrate plant tissues only through wounds due to insect injuries or some other kind of crushing or bruising, or whether they can enter through natural openings, has been the object of considerable discussion. The fact that certain leaf-spot and fruit-spot bacterial diseases appear to spread with particular rapidity during rainy seasons might be thought to favor the view that under some conditions pathogenic bacteria can enter the uninjured plant through ordinary stomata. This assumption has been fully confirmed by experiment in several affections, such as the bacterial black spot of the plum, the sweet corn disease due to Bacillus stewarti, the leaf-spot of cotton (Fig. 154), and Burrill's bacterial disease of broom-corn. Simply spraying pure cultures upon the surface of leaves or fruit is sufficient to produce the disease in these instances.

Within the plant itself the bacteria seem to be able to pass from one part to another through vessels, through the parenchymatic tissues by the way of the intercellular spaces, and directly from cell to cell. Destruction of tissue or dissolution of cell-walls does not seem necessary. Among other carefully studied bacterial

* Smith and Townsend: Centralbl. f. Bakt., II., 1907, 20, p. 89. See also Townsend: Science, n. s., Feb. 12, 1909, p. 273, and Smith: Science, n. s., Aug. 13, 1909, p. 223.

diseases of plants may be mentioned a disease of cauliflowers and allied plants described by Harrison (Bacillus oleraceæ*), a soft rot of carrots (Bacillus carotovorus†) (Fig. 157), the bud rot of the cocoanut palm in the West Indies,‡ a leaf-spot disease of broom-corn (Burrill), the so-called "gum disease" of the sugar-cane (Cobb), and a soft rot of the calla lily.§ The so-called "bacteriosis of carnations" seems not to be a bacterial disease.‖

Harrison¶ has made the interesting observation that different varieties of turnips show varying degrees of susceptibility to infection with Bacillus oleraceæ, the amount of rot present varying from less than 5 per cent. in some varieties to 65 per cent. in others. One variety seemed to be immune under natural conditions.

* Harrison: Centralbl. f. Bakt., II., 1904, 13, p. 46.

† Jones: Centralbl. f. Bakt., II., 1901, 7, p. 12, p. 61; also 1905, 14, p. 257.

‡ Smith: Science, 1905, 21, p. 535.

§ Townsend: Bull. 60, Bureau of Plant Ind., U. S. Dept. Agr., 1904.

‖ Woods: Centralbl. f. Bakt., II., 1897, 3, p. 722.

¶ Harrison: Centralbl. f. Bakt., II., 1904, 13, p. 197.

APPENDIX

INFECTIOUS DISEASES OF UNKNOWN CAUSATION

There are a number of diseases that are infectious, and therefore in all probability due to some micro-organism, but concerning the actual causation of which there is at present either much difference of opinion among competent observers or absolute uncertainty. Certain features of some of these diseases may be briefly set forth.

Smallpox.—Although vaccination against smallpox has long

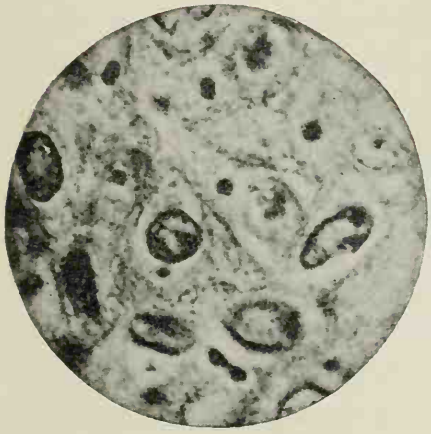

Fig. 158.—Advancing stage of smallpox vesicle; young cytoplasmic forms of parasites in the epithelial cells. × 200 (Councilman, Macgrath, and Brinckerhoff).

Fig. 159.—Intranuclear form of smallpox parasite (Councilman, Macgrath, and Brinckerhoff).

been successfully practised, no specific micro-organism has been isolated in pure culture and shown experimentally to form the basis for this procedure. Bacteria of various kinds, especially streptococci, are often found in the pustules, but it is generally believed that they are accidentally present or are secondary invaders; there is no evidence that any particular bacterial species is the primary exciting cause. The virus of smallpox and vaccinia can pass through a Chamberland filter. The epithelial cells of smallpox lesions contain peculiar bodies first regarded by Guanieri in 1892 as parasitic

protozoa, and later subjected by Councilman, Calkins, and their co-workers to thorough examination.* These later investigators regard the intracellular bodies as undoubted parasites which pass through a definite cycle in the cytoplasm of the epithelial cell (Fig. 158). Similar bodies are found in the skin lesions due to vaccination. There is this important difference, however, between the histologic appearances in vaccine lesions and those in smallpox. The affected cells in smallpox show definite nuclear changes which are interpreted as inclusions and looked upon as representing an intranuclear phase (sexual cycle?) (Fig. 159) of the parasite. In the lesions of vaccination, as they appear in man, the monkey, and other animals, no intranuclear bodies are found. Both the cytoplasmic and nuclear bodies in smallpox lesions show progressive changes which are regarded as developmental stages in the life of the parasite. The parasitic nature of these bodies has not, however, gone unchallenged. Ewing† has brought forward evidence indicating that the changes observed in the cell are forms of cell degeneration due to some kind of toxin, and are not definite parasites.

A form of smallpox (variola inoculata) which is less serious in character and effects than true smallpox has been produced in man by direct inoculation with the contents of smallpox vesicles. At one time this method of inoculation was practised to some extent in England and some other countries as a valuable means of prophylaxis, the mild attacks of the disease so engendered imparting a high degree of protection against the naturally contracted virulent type. Smallpox has been experimentally produced in monkeys by cutaneous inoculation, and manifests the same characters as inoculation-smallpox in man.

The relation between smallpox and the disease cowpox or vaccinia—a name given to a certain vesicular eruption on the udder of cows—was clearly established by the celebrated observations of Jenner in 1798. Noting that dairy workers who had had cowpox were less liable than others to contract smallpox, Jenner advocated on this and other substantial grounds the systematic inoculation of cowpox virus as a protection against smallpox. The practical success achieved by the method of vaccination is matter of common

* Jour. Med. Res., 1904, 11, pp. 1–361.

† Ewing: Jour. Med. Res., 1904, 12, p. 509; ibid., 1905, 13, p. 233.

knowledge. No one with any understanding of the nature and force of scientific evidence questions that by this means smallpox is today held in check.

It is now generally believed that the cowpox of cattle is a modified form of smallpox; indeed, typical cowpox has been produced in heifers and in rabbits by inoculation with human smallpox virus. The method of vaccination is therefore a process of active immunization with the living micro-organism of smallpox attenuated by passage through the body of the cow. Vaccine is neutralized by the serum of immunized animals, which evidently contains some substance capable of exerting a germicidal or inhibitory action upon the specific agent. Injection of immune serum seems to be without effect upon the course of a case of smallpox.

Many observers believe that the secondary infection of smallpox lesions with streptococci, which almost always, if not invariably, occurs, is more directly responsible for bringing about a fatal termination than the effects wrought by the specific parasite.

Rabies or Hydrophobia.—All mammalia are susceptible to rabic virus. Man is infected most frequently by the bite of the dog, but may also contract the disease through the bites of cats, wolves, cattle, and other animals. The bite of wolves is much more virulent than that of dogs. Bites upon the hands and face and other parts having a rich nerve-supply are most apt to result fatally. If the part bitten is covered by clothing or hair, less virus will enter the wound than if the bite is made on an exposed surface, and such bites are correspondingly less dangerous. The most reliable statistics indicate that about 16 per cent. of persons bitten by rabid dogs become infected. The virus is contained in the saliva of infected subjects, including man, and, according to Nocard and Roux, is always present in the saliva of the dog twenty-four to forty-eight hours before the animal shows any sign of illness. The virus is also always present in every part of the central nervous system, especially in the medulla. Experimentally it has been found that the virus makes its way from the point of inoculation to the central nervous system chiefly by way of the nerve-trunks. In this respect and some others rabies presents a close analogy to tetanus. The virus is readily destroyed by heat and drying and is rendered inert by direct sunlight in about forty hours.

No particularly characteristic and constant changes were found in the tissues of animals infected with rabies until Negri,* in 1903, described certain peculiar bodies as occurring in the large nerve-cells of the central nervous system. Subsequent investigators have confirmed Negri's observations, and the "Negri bodies" are now regarded as specific to hydrophobia (Fig. 160). The occurrence of these bodies, moreover, has been shown to be very important in making possible a rapid histologic diagnosis. The examination for Negri bodies may be made directly from the fresh tissues by means of the smear method. The method is as follows: After removing the top and occipital portions of the skull, leaving the brain in position, cut out small pieces (3 to 4 mm.) of the gray substance from—(*a*) the cerebral cortex in the region of the crucial sulcus, (*b*) the cortex of the cerebellum, and (*c*) the hippocampus major (Ammon's horn). Place a piece of the tissue on a well-cleaned slide, crush it with a cover-slip, and draw it slowly and evenly toward the end of the slide, leaving a thin smear of well-spread nerve-cells. The smears are then dried in the air and may be stained by various methods. Williams and Lowden† have suggested the following modification of van Gieson's stain for quick differentiation: "To 10 c.c. of distilled water three drops of a saturated alcoholic solution of basic fuchsin and 2 c.c. of Löffler's solution of methylene-blue are added. The

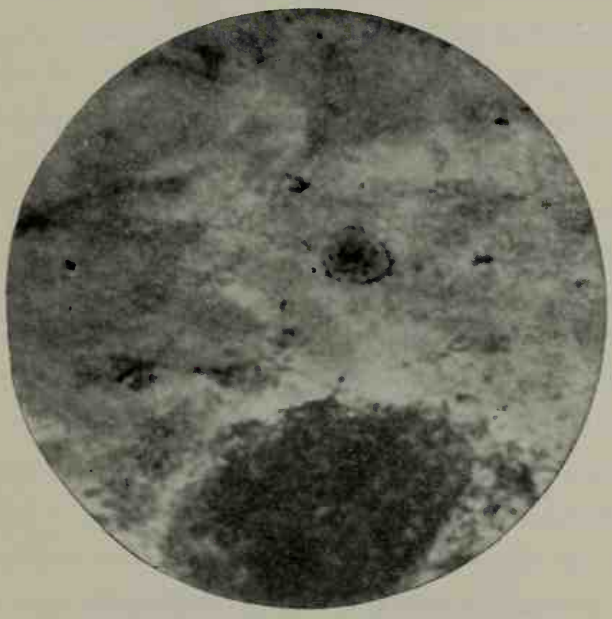

Fig. 160.—A rounded "Negri body" showing well the complete circle of chromatoid granules about the central body. From street rabies. × 2000 (Williams and Lowden).

* Negri: Boll. d. Soc. med.-chir. di Pavia, 1903, p. 88; Ztschr. f. Hyg., 1903, 43, p. 507.

† Williams and Lowden: Jour. Infect. Dis., 1906, 3, p. 452.

smears are fixed while moist in methyl-alcohol for one minute. The stain is then poured on, warmed till it steams, poured off, and the smear is rinsed in water and allowed to dry."

Negri himself has from the first maintained that these bodies are protozoan parasites, and his opinion has been shared by a number of other workers. Williams and Lowden* give the following reasons for concluding that the Negri bodies are organisms belonging to the class Protozoa: "(*a*) They have a definite, characteristic morphology; (*b*) this morphology is constantly cyclic, *i. e.*, certain forms always predominate in certain stages of the disease, and a definite series of forms indicating growth and multiplication can be demonstrated; (*c*) the structure and staining qualities, as shown especially by the smear method of examination, resemble that of certain known protozoa, notably of those belonging to the suborder Microsporidia."

The Pasteur method of treatment for hydrophobia is based upon the fact that the rabic virus in the spinal cord of rabbits loses strength at a fairly regular and even rate when the cord is removed from the body after death and carefully dried. In the preparation of material for the preventive treatment rabbits are inoculated with "fixed virus"—a term given by Pasteur to virus that is so exalted in virulence by successive passages through rabbits that it will produce the death of these animals in six or seven days. Beyond this point no increase of virulence can be obtained; hence the name, fixed virus. The spinal cord is removed aseptically from rabbits killed by the inoculation of fixed virus, cut into three pieces, and suspended over a solution of caustic potash in a drying chamber. Here the cords are kept in the dark and at a constant temperature of 23° C. for fourteen days. Emulsions of the dried cord are prepared in sterile salt solution or broth and injected every day, or sometimes more frequently, during a period of fifteen to twenty-one days, the interspacing of doses and duration of treatment being determined by the nature of the case. As a rule, the most attenuated material (fourteen-day cord) is injected first, and this is followed by virus of gradually increasing strength. Over 30,000 individuals bitten by rabid animals have been treated at the Pasteur Institute in Paris, with a mortality of less than 1 per cent., figures that prob-

* Williams and Lowden: Jour. Infect. Dis., 1906, 3, p. 452.

ably mean the saving of the lives of between two thousand and three thousand persons. The method is essentially one of active immunization, and involves a race between the action of the attenuated virus and the virulent virus introduced by the bite of a rabid animal. It follows that the preventive treatment must always be begun at the earliest possible moment after the bite. In a certain proportion of cases a spinal cord lesion seems to follow the treatment. The pathogenesis of this condition is unknown. A fatal result is rare.*

The serum of animals immunized against hydrophobia possesses considerable protective power, and according to some investigators, has also a marked curative effect. Favorable results have been reported from the use of immune serum, especially in cases of severe bites about the head, or in persons who have delayed beginning the Pasteur treatment.†

Since nearly all cases of hydrophobia are due to the bite of rabid dogs, it is of the utmost importance to check the spread of the disease in these animals. This can be most effectively and humanely accomplished by the strict enforcement of proper muzzling regulations. The experience of Great Britain is worth citing.

Year	Cases of Rabies
1887	217
1888	160
1889	312
Muzzling enforced:	
1890	129
1891	79
1892	38
Opposition to muzzling; ordinance relaxed:	
1893	93
1894	248
1895	672
Muzzling again enforced:	
1896	438
1897	151
1898	17
1899	9
1900	6
1901	1
1902	13
1903–07	0

* W. A. Jones: Jour. Amer. Med. Assoc., 1909, 53, p. 1626.

† Tizzoni and Centanni: (Abs.) Centralbl. f. Bakt., 1895, 18, p. 240.

Yellow Fever.—This disease is peculiar to man: under natural conditions none of the lower animals suffer from it. The chimpanzee, however, has been infected experimentally.* Yellow fever is primarily a disease of the tropics, but is occasionally introduced into the temperate zone, where it can flourish prodigiously for a time until checked by the occurrence of frost. The infectious character of yellow fever has long been manifest, and for many years the belief prevailed among many physicians that the disease could be disseminated through the atmosphere. Others, however, maintained that it was directly contagious, or, at any rate, could be communicated through clothing, bedding, and the like. The confusion that existed as to modes of transmission was first dispelled by the experimental work of Reed, Carroll, Agramonte, and Lazear.† These investigators showed that the bite of a particular species of mosquito (Stegomyia calopus) (Fig. 161) could communicate the disease, thus furnishing proof of a theory advanced by Finlay in 1881,‡ and earlier by Nott.§

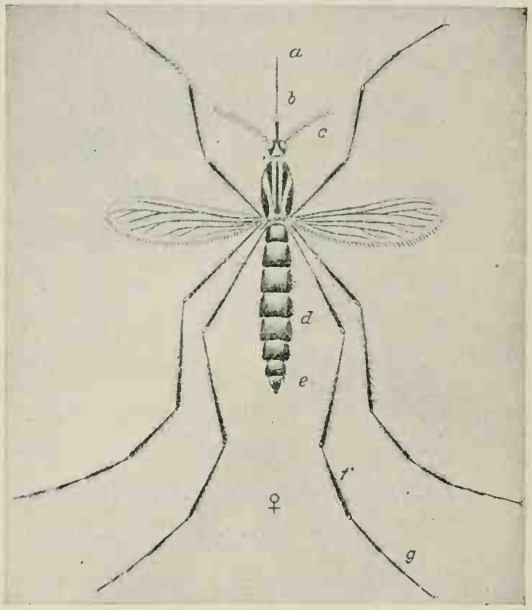

Fig. 161.—Stegomyia calopus, female. × 8. *a*, Proboscis; *b*, palpi; *c*, antenna; *d*, femur; *e*, tibia; *f*, metatarsus; *g*, tarsus (Otto).

The evidence in favor of mosquito transmission is briefly as follows: Men volunteering to submit themselves to experimentation were first subjected to a period of strict quarantine and then were exposed to the bite of mosquitos that had previously bitten yellow fever patients. They then returned to quarantine. In the majority of instances an attack of yellow fever followed the mosquito bite

* Thomas: Brit. Med. Jour., 1907, 1, p. 138.

† Phil. Med. Jour., 1900, 6, p. 790; Rep. and Papers, Amer. Pub. Health Assoc., 1900, 26, p. 37.

‡ Finlay: Jour. Amer. Med. Assoc., 1901, 37, p. 1387.

§ Nott: New Orleans Med. and Surg. Jour., 1848, 4, p. 580.

in about five days. Further experiments showed that the subcutaneous injection of 0.5 c.c. of blood drawn directly from the veins of a yellow fever patient on the first or second day of the disease would cause an attack of yellow fever. The blood-serum is still infectious after it has been passed through a Berkefeld filter (Carroll). It was also found that a certain period—at least twelve days—must elapse after a mosquito had bitten a yellow fever patient before the insect could communicate the disease. This is taken to indicate that the virus of yellow fever passes through a developmental cycle in the body of the mosquito, and is hence, from analogy, to be regarded as of a protozoan rather than of a bacterial nature. A mosquito once infected remains so during life. The ability to transmit yellow fever is limited, so far as known, to one particular species, *Stegomyia calopus*, having a world-wide distribution, but restricted in its breeding to warm climates (43° S. to 43° N. latitude).

Many experiments have been made to determine whether yellow fever can be communicated in any other way than by the bite of the mosquito. Volunteer experimenters have lived and slept in closest contact with clothing and bedding used by yellow fever patients. "One of them slept with his head upon a towel soiled with blood drawn from a patient in the first day of the disease, and which was shown by inoculation to be capable of infecting" (Carroll). All of these attempts to produce infection from the yellow fever patient or his belongings without intervention of the mosquito have failed, and there is today no evidence of transmission other than through the medium of the mosquito.

The nature of the micro-organism causing yellow fever is unknown. Although the blood of patients is infectious, no specific bacterium has been cultivated from the blood nor is any seen in stained preparations. On exposure to air the blood loses within two days its power to infect. The analogy of yellow fever to malaria has already been mentioned. The lapse of a definite period is necessary before an infected mosquito can become capable of producing infection, and the length of this period is determined in large part by the temperature at which the mosquito is kept. The occurrence of the disease is dependent upon the presence of a particular insect and a particular mammal, a fact that, like the foregoing, seems to point to the presence of a parasite of the animal kingdom with a sexual cycle in one and an asexual cycle in the other host.

The most satisfactory method that has been found of combating yellow fever is to attack the mosquito host. *Stegomyia* is seldom found far from human habitation, and breeds by preference in artificial collections of water, especially in rain-water cisterns and barrels. Destruction of larvæ with oil, and of the adult insects by sulfur fumigation, combined with the elimination or screening of possible breeding-places, are measures that have been employed with great success. Mosquitos should also be barred from all possible avenues of approach to yellow-fever patients.

In Havana, Cuba, during the year 1900–1901, "when the sanitary authorities were putting forth every effort known at that time to sanitary science in order to control the march of the disease," the yellow-fever cases numbered 1240 and the deaths 305; in the following year, 1901–1902, when "yellow fever was fought on the theory that the specific agent of this disease is transmitted solely by means of the bites of infected mosquitos," there were 31 cases and 6 deaths.*

Whooping-cough.—Bacilli resembling B. influenzæ have been reported by various observers as occurring in a large proportion of cases of whooping-cough. Although there are minor differences in the descriptions of these organisms as given by different observers, the cultural and morphologic characters are essentially similar, and there seems little doubt that Spengler, Jochmann and Krause, Wollstein, and Davis† have had the same bacillus in hand. Owing to the close resemblance to, if not identity of this organism with, the influenza bacillus, there has been considerable reluctance among bacteriologists to accept it as the cause of whooping-cough.

Bordet and Gengou‡ have found a short oval bacillus in the bronchial exudate from cases of whooping-cough. It is present in great numbers in the early stages of the disease. It is at first grown with difficulty on a special medium devised by Bordet and Gengou, consisting of 1 per cent. glycerin-agar or broth made with macerated potato and added to an equal volume of human or rabbit blood. After some generations on this medium it will grow on the surface of ascitic-fluid agar in a whitish, elevated streak which does not spread much over the surface. It is Gram-negative and shows

* Reed: Jour. of Hyg., 1902, 2, p. 101.

† Davis: Jour. Infect. Dis., 1906, 3, p. 1.

‡ Bordet and Gengou: Ann. de l'Inst. Past., 1906, 20, p. 731.

polymorphism in fluid media. The bacillus of Bordet and Gengou is agglutinated by the serum of convalescents from whooping-cough, although with great inconstancy. The serum of convalescents also shows the presence of a specific substance by giving the reaction due to "deviation of complement" (p. 157). This property is constant. The bacillus has a distinct toxic action upon the tissues of the guinea-pig and rabbit.

Klimenko* found the Bordet-Gengou bacillus in 80 per cent. of the children (76 in number) that he examined during the first week of the disease. He also succeeded in reproducing the disease with pure culture in 48 young dogs and in monkeys.

Scarlet Fever.—Streptococci are almost always, perhaps invariably, present in the throats of scarlet fever patients, and are often present in the blood of severe cases, and this has led some observers to adopt the conclusion that a special variety of streptococcus is the cause of the disease. The majority of investigators, however, incline to the opinion that in scarlet fever, as in smallpox, streptococci are present as secondary invaders, and are not the primary exciting cause. No constant cultural and morphologic characters distinguish the streptococci isolated from scarlet fever from those from other sources, and inoculation experiments made with cultures of scarlet fever streptococci have failed to reproduce the disease.

Fig. 162.—A large granular scarlet fever body and a rosette in an early stage of development in epithelial cells (Mallory).

Mallory* has found peculiar bodies that resemble protozoa in the skin of scarlet fever cases. These are of definite shape and structure, sometimes showing rosette forms, and there is strong reason for supposing that they have an etiologic significance (Fig. 162). At all events, they are characteristic of the disease, and so far as known are associated exclusively with it.

Measles.—This disease is not communicable to the lower animals, even monkeys giving negative results in inoculation experiments.

* Klimenko: Centralbl. f. Bakt., I., 1908.

† Mallory: Jour. Med. Res., 1904, 11, p. 483.

Hektoen* has shown that the specific agent is contained in the blood. Blood drawn from the veins of a measles patient and mixed with ascites broth was found to give no visible growth when incubated at 37° C. for twenty-four hours. A few cubic centimeters of this mixture injected into a healthy man produced the typical symptoms and eruption after the usual period of incubation.

No micro-organism has been found that can be suspected, with even a fair degree of probability, of causing the infection.

Foot-and-mouth Disease.—A disease of cattle and other domestic animals, characterized especially by the appearance of a vesicular eruption on the mucous membrane of the mouth and on the skin of the hoof or between the toes, has long been known in parts of Europe. On several occasions it has been imported into the United States, the last recorded outbreak being in Michigan, Pennsylvania, and a few neighboring States in 1908. This outbreak started from calves, in Detroit, that had been used in the propogation of small-pox vaccine virus. The vaccine used came from a foreign country, and investigation showed that the original strain was contaminated with the virus of foot-and-mouth disease. The stamping out of the disease cost about $300,000 and was brought about by the slaughter of infected animals and by the application of rigorous methods of quarantine and disinfection.† The disease may be communicated to man by milk or milk-products or by contact with infected animals. Among cattle the mortality is apt to be high, especially in young animals. In man the disease is usually of a mild type, but is sometimes fatal in children.

No specific micro-organism has been found in the disease. It has been demonstrated, however, by Löffler and Frosch,‡ that the disease can be produced by the inoculation of lymph from the vesicles after the lymph has been filtered through the finest Berkefeld filters. On this ground the cause of the disease has been classed as an "ultramicroscopic virus." The virus retains its virulence for months if kept cool and moist, but is rapidly destroyed by a temperature of 60° C. and by drying. A protective substance exists

* Hektoen: Jour. Infect. Dis., 1905, 2, p. 238.

† Frothingham: Bost. Med. and Surg. Jour., 1903, 148, p. 9.

‡ Löffler and Frosch: Centralbl. f. Bakt., I., 1898, 23, p. 371.

in the serum of animals convalescent from the disease, and in experimental work the principle of passive immunization can be successfully practised.

Rocky Mountain Spotted Fever.—This remarkable disease is restricted, so far as known, to a few localities. It is best known and apparently most fatal in the Bitter Root Valley of Montana, but occurs also in the mountainous parts of the neighboring States.

The first important study of the disease was made by Wilson and Chowning.* These authors attributed the disease to a protozoön (Piroplasma), but the microscopic findings on which they based this opinion have not been confirmed by subsequent observers. Wilson and Chowning also suggested that the bite of the woodtick might be the means of conveying the disease. Communication by tick-bites was later experimentally demonstrated by King† and by Ricketts.‡ Extended and fruitful investigations have been carried out by Ricketts,§ who has shown that the disease can be communicated to monkeys and guinea-pigs by the intraperitoneal injection of defibrinated blood of typical cases, and also by the bite of ticks that have fed on spotted fever patients. Both male and female ticks can transmit the disease. The virus can be kept alive in the laboratory either by alternate inoculation of monkey and guinea-pig or by continuous passage through the guinea-pig. In the latter animal the maximum infectivity of the blood seems to be between the third and fifth day after the beginning of fever. Ricketts and Gomez‖ have shown that an attack of spotted fever in the guinea-pig and monkey produces a high and lasting active immunity which is characterized by the presence of protective antibodies in the serum. Passive immunity may be conferred by the injection of blood or serum from immunized animals, or by a mixture of such serum with virus. The curative power of the serum is low.

Mumps.—A diplococcus was found in the exudate of the parotid gland by Laveran and Catrin¶ in a large proportion of all cases

* Wilson and Chowning: Jour. Amer. Med. Assoc., 1902, 39, p. 131; Jour. Infect. Dis., 1904, 1, p. 31.

† King: Public Health Reports, July 27, 1906.

‡ Ricketts: Jour. Amer. Med. Assoc., 1916, 47, p. 358.

§ Ricketts: Jour. Infect. Dis., 1907, 4, p. 141.

‖ Ricketts and Gomez: Jour. Infect. Dis., 1908, 5, p. 221.

¶ Laveran and Catrin: Compt. rend. de la Soc. biol., 1893, p. 95.

examined. Other investigators have found a similar diplococcus in the gland exudate and in the blood in cases of mumps. Korentschewsky* obtained a diplococcus from the exudate in twenty-one out of twenty-nine, and from the blood in eight out of thirty-two cases. A diplococcus isolated by Isabella Herb† shows the following characteristics: It averages from 0.5 μ to 1.5 μ in diameter, stains easily with the ordinary anilin dyes, and is gram-positive. It has no capsule. Development takes place on all the ordinary media, but is very slow, the colonies on glycerin-agar being scarcely visible in twenty-four hours. Gelatin is very slowly liquefied. Milk is coagulated in forty-eight hours. Mixing sterilized saliva with agar, as in making blood-agar, gives a favorable medium, and in twelve to twenty-four hours an abundant growth occurs. This diplococcus apparently corresponds with the organism isolated by Laveran and Catrin. Miss Herb's inoculation experiments are significant. "Inoculations of suspensions of the diplococcus into Steno's duct in the monkey and in the dog produce an acute, uniform enlargement of the parotid gland, accompanied with some slight fever. In the dog this enlargement is the result of an infiltration that consists largely of mononuclear cells, and is accompanied with a general increase in the mononuclear cells in the blood, as well as a distinct rise in the opsonic index with respect to the diplococcus."

Epidemic Infantile Paralysis (Acute Poliomyelitis, Heine-Medin Disease).—This disease was recognized as a specific malady more than fifty years ago by Jacob v. Heine. In more recent times attention became especially directed to it through the Swedish outbreaks of 1899 and 1905 (1000 cases), which were carefully investigated by Medin. The malady has since appeared in several parts of the United States‡ and in Germany. Young children from one to two years old seem most liable to attack, adults being seldom affected. The mortality ranges from 6 to 15 per cent. It is spread from person to person through contact. There is no doubt it is an acute infectious disease. Flexner and Lewis§ succeeded by the method of intracranial inoculation in

* Korentschewsky: Centralbl. f. Bakt., I., 1907, 44, p. 394.

† Herb. Isabella: Archives of Int. Med., Sept., 1909.

‡ Starr: Jour. Amer. Med. Assoc., 1908, 51, No. 2.

§ Flexner and Lewis: Jour. Amer. Med. Assoc., 1909, 53, p. 1639.

carrying the virus through a series of monkeys. In all the successive transfers lesions similar to those of human poliomyelitis were observed. Krause's observations point to the gastro-intestinal tract as the portal of entry of the infecting agent.* Guinea-pigs, mice, and pigeons fed with intestinal contents from typical cases of infantile paralysis gave negative results. Rabbits, on the other hand, can be fatally infected.† Attempts to discover by the usual methods the exciting micro-organisms have so far failed. The experiments of Flexner and Lewis‡ indicate that the infecting agent belongs to the class of minute, filterable viruses which have not thus far been demonstrated with certainty under the microscope.

* Krause: Deutsch. med. Wochenschr., 1909, 35, p. 1822.

† Krause and Meinicke: Deutsch. med. Wochenschr., 1909, 35, p. 1825.

‡ Flexner and Lewis: Jour. Amer. Med. Assoc., 1909, 53, p. 2095.

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